MINISTRY OF LANDS, SURVEY AND NATURAL RESOURCES

KINGDOM OF TONGA

THE HYDROGEOLOGY AND WATER SUPPLY

OF

THE KINGDOM OF TONGA

by

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and

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Preface

An assured supply of fresh water - a subject regarded with indifference by many a city dweller - is not always so certain or accessible for village communities throughout the Tongan archipelago who depend on the vagaries of the weather and fragile underground aquifers for this resource.

Water storage and management has been an important focus of Australia's bilateral aid programme to Tonga over a number of years. This assistance has included a survey of Tonga's underground water reserves, the provision of ferro-cement and fibre glass water tanks to village communities throughout the country and technical support to the Tonga Water Board to improve the supply of water to Nuku'alofa and neighbouring centres.

The appointment of the Australian hydrogeologist, Mr Lindsay Furness, to the Tongan Ministry of Lands, Survey and Natural Resources from 1990 to 1993 has been a further part of this programme of Australian assistance. During his assignment Mr Furness travelled extensively throughout the country - to every island in the Tongan group, in fact, where there is permanent habitation - assessing the extent and quality of local water supplies and suggesting ways for the optimal use and protection of these reserves. For many parts of Tonga his work represented the first time that such a thorough and scientific investigation of local water resources has ever been carried out.

The following study by Mr Furness is his summation of these labours of three years. It is a valuable document for future water management in Tonga and testimony to his professional dedication and his commitment to the Tongan people.

H C Brown
Australian High Commissioner
Nuku'alofa
26 January 1993

1.SUMMARY

An investigation into the hydrogeology and water supply of the Kingdom of Tonga was carried out from 1990 to 1992. The report outlines the characteristics of each inhabited island by their natural groupings. In general, they are very small to small islands made up of uplifted coral limestone with a volcanic ash soil. Most support a fresh water lens which is utilised for water supply.

Throughout the Kingdom, rain water from a relatively high (1700 to 2300 mm) and reliable pattern is the primary source of potable water. The hardness of the groundwater makes it less palatable and it is used mainly for washing and sanitation. Collection of rain water has been facilitated by tanks of galvanized iron, reinforced concrete and fibre glass. There have been numerous programs involving the installation of water catchments and tanks.

The main concern in assessing the groundwater has been the quality of the water. A picture of the degree of saline intrusion into the fresh water lens was obtain from a census and sampling of wells throughout the Kingdom. Testing for pesticides was carried out in wells of Tongatapu in 1991. Only trace amounts were found in three wells.

Monitoring of water levels in three wells, together with sea level and lagoon gauging, barometric pressure and rainfall has enabled direct assessment of the pattern and amount of recharge to the aquifer.

Geophysical methods, including Electromagnetics (EM) and Resistivity were employed in the search for fresh water on the islands of Ha'apai. The EM technique was particularly useful in mapping contrasting areas of fresh and salty groundwater. This lead to the identification of a new water supply for Lifuka, the main centre of population in Ha'apai.

The report looks at the geography of the Kingdom of Tonga in Section 3, describing the physical features of the islands, the population, land tenure and use. In Section 4 the various climatic features which influence the Hydrological Cycle as it applies in Tonga are outlined. Section 5 describes the geological framework and the soils. Section 6 gives a detailed description of the hydrogeology of each of the inhabited islands, group by group. A hydrogeological map of each island is accompanied by facts about the water supply and there are notes on possible improvements.

2. ACKNOWLEDGEMENTS

The following report is dedicated to the memory of Elwyn Furness and to Professor John Holmes.

Work on the Hydrogeology of Tonga was financed under the Australian Staffing Assistance Scheme. The first author took part in this Scheme to assist the Ministry of Lands, Survey and Natural Resources from 1990 to 1993.

With great respect, we thank the Honorable Dr. S. Ma'afu Tupou, Minister of Lands and Sione L. Tongilava, Secretary for Lands, Survey and Natural Resources. Saimone Helu, Government Geologist was the counterpart for the position of Hydrogeologist. Assistance was provided by the staff of the Geology Section; Sione Soakai, Tevita Fatai, Rennie Vaiomo'unga and Mikale 'Apikotoa.

Lelea Tuitupou, Senior Health Inspector of the Ministry of Health liaised with the village water committees. Kupa Tuivai of the Ministry of Works organised the drilling program. Soeli Latu was the driller.

During the enjoyable years in the Kingdom numerous people gave assistance throughout the islands visited. The town officers of many villages organised delicious feasts which sustained the drilling team.

To all others who at any time provided help, a smile or showed interest in the work, we thank you, one and all.

Malo 'Aupito,
'Ofa atu.

3. INTRODUCTION

3.1 Background

Since the early 1980's it was recognised by the Ministries of Health, Lands, Survey and Natural Resources and the Tonga Water Board, that the Kingdom of Tonga lacked an understanding of the underground water resources which provide the vital supplies to the majority of the population. Several experts had visited the country over the years on short trips and provided reports on their interpretations of the country's water resources. Many of the reports reiterated the need to carry out a hydrogeological study and institute a regular monitoring program.

Early attempts to obtain the services of a hydrogeologist to advise the Government were not successful, however, the Ministry of Health placed a moratorium on the drilling of new wells until a hydrogeologist could be recruited.

In 1989 the Australian Department of Foreign Affairs approved a request and undertook to place a hydrogeologist in the Ministry of Lands, Survey and Natural Resources under the Australian Staffing Assistance Scheme. In that same year the Government Geologist of the Ministry of Lands, Survey and Natural Resources underwent training in Israel in hydrogeology.

3.2 Location and description

The Kingdom of Tonga is a Polynesian country which lies in the South West Pacific between Fiji, Western Samoa and New Zealand (Fig. 3.2a) On August 24th, 1887 King George Tupou I, the first king of Tonga declared the Kingdom's boundaries as Longitudes 177^0W and 173^0W, and Latitudes 15^0S and 23^0 30'S (Fig 3.2b)

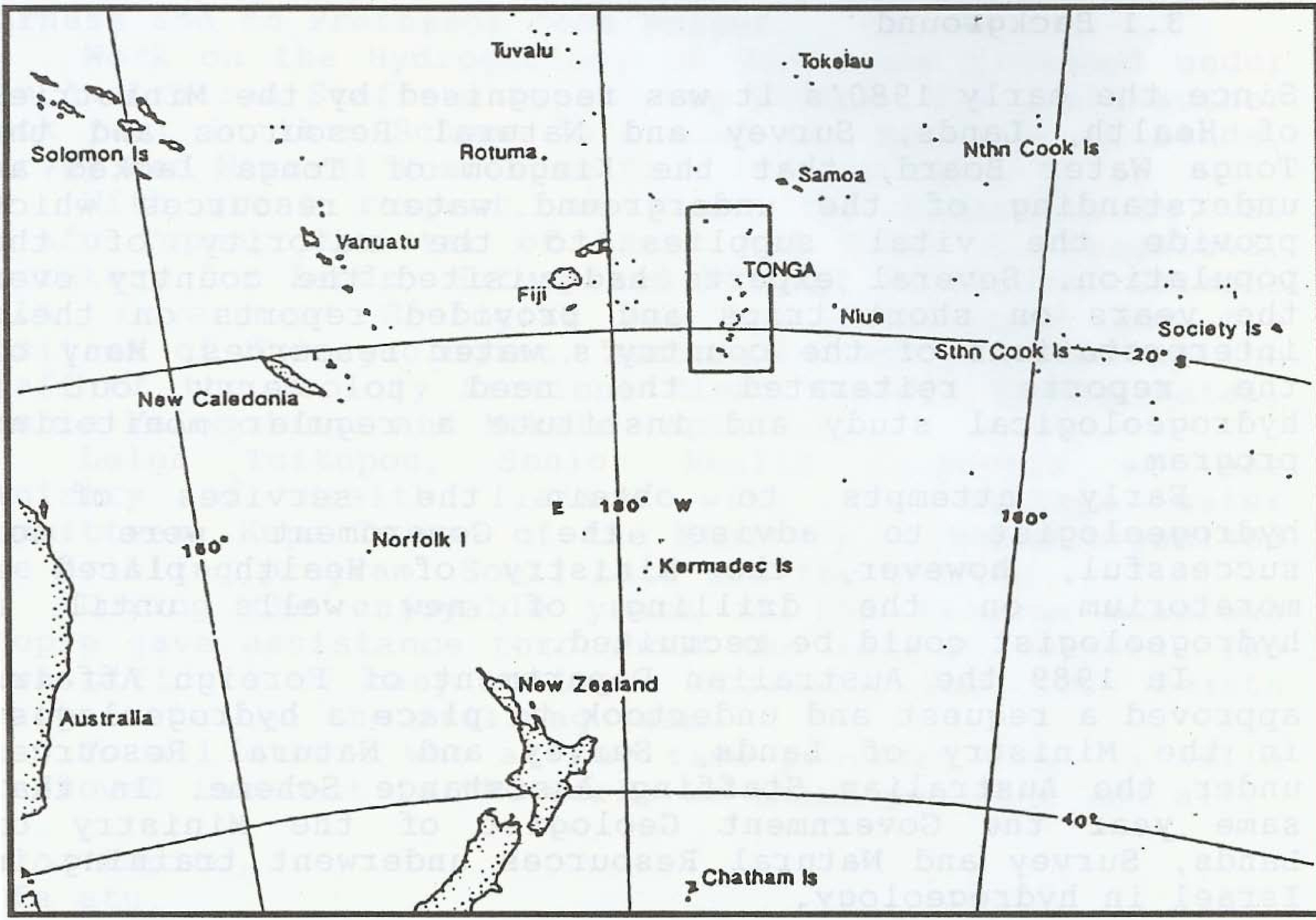
Tonga comprises some 176 islands of which 35 are inhabited. They are spread over a great expanse of the Pacific Ocean, forming an archipelago aligned from the 176th to the 174th meridian. These islands were believed by the ancient Tongans either to have fallen from the sky or to have been raised from the sea on the hook of the god Maui. Now they are home to 100,000 Tongans living on the riches of the soil and the sea.

The islands are recognised as either volcanic or uplifted coral limestone on a deep pile of sediments of volcanic origin. The volcanos form a linear chain on the western side and the coral islands to the east.

Volcanic islands are recently formed and several are currently dormant or slightly active. Undersea eruptions have occurred in recent years and lava flows on Late, Fonualei and Niua Fo'ou appeared this century.

The limestone islands have been uplifted in blocks in response to crustal movements. During this uplift, which

LOCATION OF THE KINGDOM OF TONGA



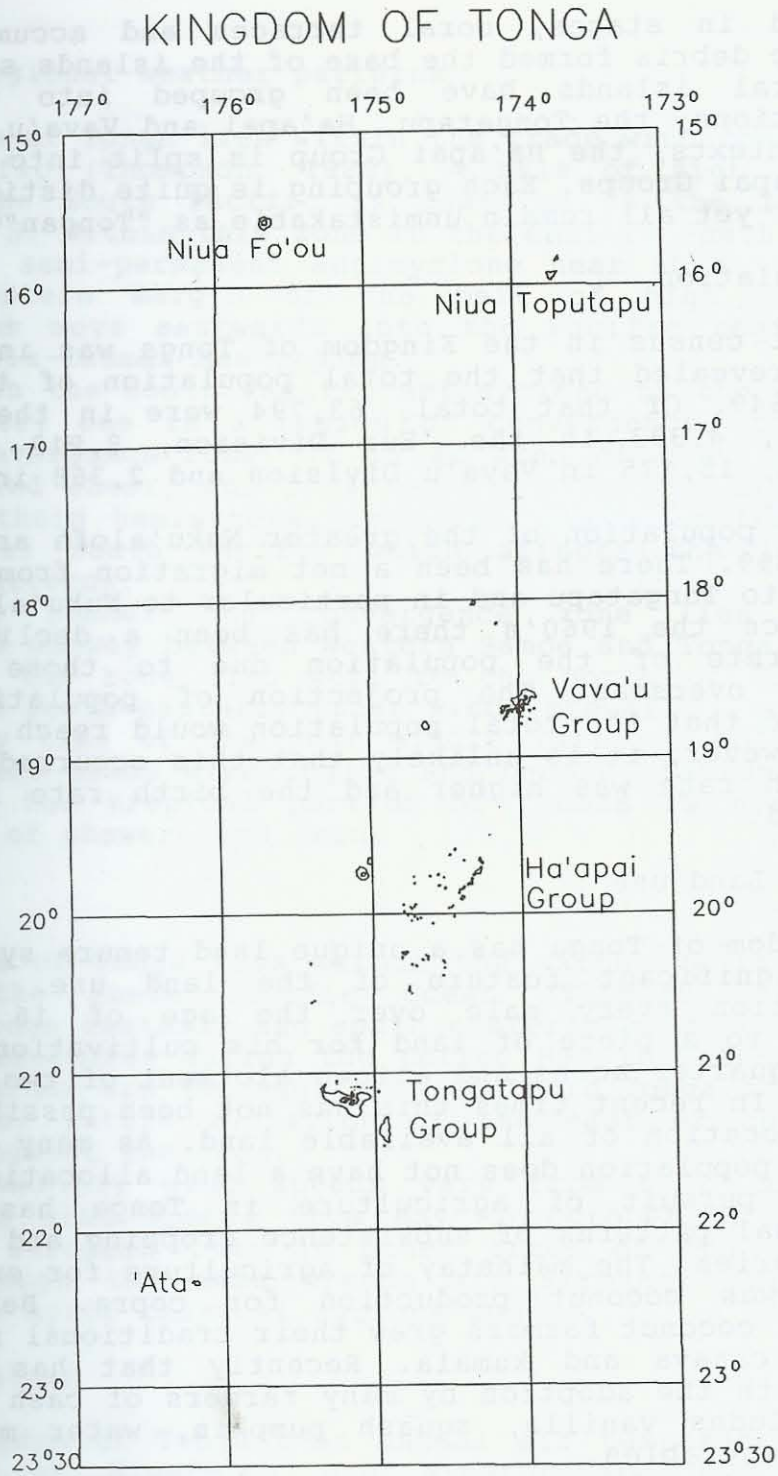

KINGDOM OF TONGA
177⁰
176⁰
175⁰
174⁰
173⁰
15⁰
16⁰
17⁰
18⁰
19⁰
20⁰
21⁰
22⁰
23⁰
23⁰30
Niua Fo'ou
Niua Toputapu
Vava'u Group
Ha'apai Group
Tongatapu Group
Ata

Fig. 3.2b

occurred in stages, coral terraces and accumulation of volcanic debris formed the base of the islands seen today.

Coral islands have been grouped into three main associations; the Tongatapu, Ha'apai and Vava'u Groups. In some contexts, the Ha'apai Group is split into the Nomuka and Ha'apai Groups. Each grouping is quite distinct in many aspects, yet all remain unmistakable as "Tongan".

3.3 Population

The last census in the Kingdom of Tonga was in 1986. The census revealed that the total population of the Kingdom was 94,649. Of that total, 63,794 were in the Tongatapu Division, 4,393 in the 'Eua Division, 8,919 in Ha'apai Division, 15,175 in Vava'u Division and 2,368 in the Niuas Division.

The population of the greater Nuku'alofa area in 1986 was 28,899. There has been a net migration from the outer islands to Tongatapu and in particular to Nuku'alofa.

Since the 1960's there has been a decline in the growth rate of the population due to those who have migrated overseas. The projection of population growth estimated that the total population would reach 100,000 by 1990, however, it is unlikely that this occurred. The out-migration rate was higher and the birth rate lower than predicted.

3.4 Land use

The Kingdom of Tonga has a unique land tenure system which is a significant feature of the land use. Under the constitution every male over the age of 16 years is entitled to a piece of land for his cultivation of eight and one quarter acres and a town alotment of two fifths of an acre. In recent times this has not been possible due to the allocation of all available land. As many as 43% of the male population does not have a land allocation.

The pursuit of agriculture in Tonga has followed traditional patterns of subsistence cropping and fallowing for centuries. The mainstay of agriculture for export this century was coconut production for copra. Beneath the canopy of coconut farmers grew their traditional root crops of yam, casava and kumala. Recently that has begun to change with the adoption by many farmers of cash cropping. This includes vanilla, squash pumpkin, water melons and western vegetables.

With the advent of cash crops comes the question of irrigation using groundwater sources. To date there has been little activity in the arena of irrigation. The need to irrigate has been offset by the usually frequent rain, even during the dry season, and the high capital cost of an irrigation system. However, recent droughts and the entrepreneurial talents of a few farmers has introduced supplementary watering on Tongatapu.

4. CLIMATE

4.1 Regional weather patterns

The Kingdom of Tonga lies within the trade wind zone of the South Pacific (Thompson, 1986). A belt of high pressure spanning the South Pacific is centered on the latitudes 25^0S to 30^0S. Within this zone in the eastern South Pacific is a large semi-permanent anticyclone near 90^0W to 100^0W. On the western margin of the belt of high pressure, anticyclones move eastwards into the Pacific region from the Australia-Tasman Sea region.

Between the South Pacific anticyclone to the east and the migratory one is a region of convergence, the South Pacific Convergence Zone. It is an area of convergence of cyclonic wind shear, and is a semi-permanent cloud feature of the southern hemisphere. It is an important feature of the tropical South Pacific which affects the long-term rainfall patterns.

During summer the convergence zone lies between Vanuatu and midway between Western Samoa and Tonga. During the winter the zone lies well to the north of Tonga and easterly or south-easterly trade winds prevail.

At any time of the year middle latitude cold fronts may enter the trade wind region and become stationary. The weather of the tropical portion of fronts is normally a broad band of showers and rain.

4.2 Wind

The Kingdom of Tonga lies within the extensive trade wind zone of the South Pacific Ocean (Thompson, 1986). In northern Tonga easterly and south easterly winds have their highest frequencies during the period May to October, when the trade winds are strongest. In southern Tonga there is a tendency for little variation of the east or south-east winds throughout the year.

Mean monthly wind speeds vary from four to eleven knots. Mean wind speeds from May to October in northern Tonga are stronger than at other times of the year. In southern Tonga the mean speeds are stronger during the November to April tropical cyclone season.

4.3 Temperature

In the Kingdom of Tonga mean annual air temperatures vary from 26^0C at Niuafo'ou and Niuatoputapu to 23^0C on Tongatapu. There is an increase in daily and seasonal variation with increasing latitude. Niuatoputapu has an average daily range of 6^0C, and a seasonal range of 2^0C. Nuku'alofa has corresponding values of 6^0C and 5^0C respectively.

Daily maximum and minimum temperatures are highest in February and least in July or August.

4.4 Precipitation

There is a marked seasonality in the Tongan rainfall (Thompson, 1986). There are two main seasons; a wet season from November to April and a dry season from May to October. About 65 per cent of the rain falls during the wet season. Rainfall seasonality is most marked on the Ha'apai and Vava'u groups. Table 4.4 shows the mean rainfall in the major island groups.

TABLE 4.4 MEAN MONTHLY AND ANNUAL PRECIPITATION (mm)

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Nuku'alofa (1770)	204	238	224	169	100	91	96	106	131	131	121	163
Pangai (1716)	203	197	284	190	107	76	94	96	110	100	110	164
Neiafu (2231)	274	262	347	220	141	111	113	102	132	132	167	232
Niua Topu-tapu(2301)	271	249	283	255	160	114	115	84	129	178	213	241

Precipitation results from convective processes, from tropical cyclones and from rain associated with cloud sheets of the subtropical jet-stream. The northern most islands which come under the influence of the South Pacific Convergence Zone have the highest precipitation.

The Ha'apai group lies in a relatively dry zone, of Tonga between the region of influence of the convergence zone and the rainfall associated with upper air jet-stream and other extra-tropical weather features.

On Tongatapu the rainfall slightly increases to the higher south east side of the island. 'Eua has a slightly higher rainfall than Tongatapu due to the orographic influence. There may be a higher rainfall on the east and a rainshadow effect on the west.

A detailed analysis of rainfall statistics is provided in Falkland (1991a).

4.5 Humidity

The high water content of the tropical atmosphere is influenced by the warm air masses of the tropics and by the presence of sea temperatures that generally exceed air temperatures. The relative humidity varies between about 65 and 95 percent. Lowest humidities are in the early afternoon when temperatures are highest.

4.6 Evapotranspiration

The Penman estimates of evapotranspiration have been calculated by Thompson (1986), and are given in Table 4.6.

Table 4.6 ESTIMATE OF PENMAN POTENTIAL EVAPOTRANSPIRATION (mm/month)

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Niua Fo'ou	144	133	141	114	110	99	106	118	129	140	142	150
Niua Topu-tapu	149	130	138	112	108	99	106	116	129	143	148	152
Vava'u	151	134	135	112	103	90	99	108	117	142	151	159
Ha'apai	161	144	145	113	103	89	101	109	121	145	156	161
Nuku'alofa	164	137	139	108	89	77	85	96	116	144	152	154
Pan Vaini	179	168	142	133	117	93	118	127	165	185	198	185

Comparison with the rainfall shows that there is sufficient precipitation in most months to meet the evapotranspiration demand. The soil water balance can be calculated on a monthly basis (Thompson, 1986) or using daily values (Falkland, 1991a). The available water content of the soils varies between 90 and 160 mm (Wilson and Beecroft, 1983, Wilde and Hewitt, 1983).

Recharge and soil moisture deficit occur throughout the year. The amount of recharge tends to be largest in the wet season, and soil moisture deficits are greatest at the end of the dry season.

4.7 Barometric pressure

The barometric pressure in Tonga is typical of the tropical situation with a daily fluctuation on a 12 hour cycle with amplitudes of around two millibars. Maximum pressures are at 1000 and 2200 hours local time. There tends to be a cycle of roughly one week during the passage of broad low pressure troughs with a larger fluctuation of five to ten millibars.

The inverse relationship between sea level and atmospheric pressure (Pugh, 1987) is seen in the response of tide gaugings in Nuku'alofa. The theoretical response of an increase in barometric pressure of one millibar causing a decrease in sea level of one centimetre is closely approximated.

During a year the atmospheric pressure may typically vary between 980 and 1030 millibars.

4.8 Tropical cyclones

Tropical cyclones are experienced in Tonga mainly during the wet season from November to April. Between November 1939 and April 1985 there were seventeen cyclones affecting the whole of Tonga. Forty one cyclones affected only northern Tonga and thirty eight in southern Tonga.

There is an average of 1.3 cyclones per year in northern and southern Tonga.

4.9 Meteorological recordings

Climate monitoring is carried out in Tonga through the Department of Meteorology under the Ministry of Civil Aviation. In addition, the Ministry of Agriculture and Forests have a climate recording station at their Vaini Research Farm on Tongatapu. Pluviometers and water level recorders were installed for the current project at Mataki'Eua well field on Tongatapu, at Fua'amotu International Airport, at 'Anapekepeka on 'Eua and at Hihifo, Ha'apai. A barometer was included in the instrumentation at Mataki'Eua.

4.10 Sea level

The sea level has an important bearing on the hydrogeology of Tonga. Changes in sea level from tidal, barometric, El Nino and climate change have an influence on water levels, mixing of fresh water and salt water, and the elevation of the water table. For these reasons, tide gauging was re-established at Vuna Wharf in Nuku'alofa in 1990. In addition, temporary gauging stations were used in Ha'apai, Vava'u and the Fanga'Uta Lagoon.

Initial chart datum was established for surveys by HMS Egeria in 1880. It was established as being 9.80 feet below a benchmark cut in the west face of Prince Wellington's Monument, then located in the palace grounds. The monument was moved to Ha'apai in 1989.

HMNZS Lachlan carried out surveys in Nuku'alofa in 1957 and 1958, establishing a new benchmark in the wall of the copra shed on Vuna Wharf. An error was made in the levelling and values related to the 1957 pole are suspect.

Tidal observations were carried out by D.L. Leach in 1962 and included a plan of local control points and bench marks with their reduced levels.

Subsequent to the earlier surveys, there was a major earthquake in 1977 (magnitude 7.2 on the richter scale) which badly damaged the Vuna Wharf and the bench marks on the copra shed.

In 1990 it was found that many of the benchmarks on Tongatapu were lost or moved. In consultation with the Hydrographer at the Tonga Defence Services a tide gauge was re-established on the Vuna Wharf in the same location as the 1957 gauge. A chart water level recorder was installed in May 1990 and levelled in to the existing bench marks and a new Fundamental Bench Mark. The position and elevation of the tide gauge was also established using the Global Positioning System.

Mean sea level was obtained for the period June-July, 1990 and was adopted as an interim level for surveying. The mean sea level was transferred by first and second order levelling to a system of permanent bench marks established at frequent intervals around the island. From these bench marks the elevations of wells and water levels were obtained. Mean sea level of June-July 1990 was found to be 0.218 metres below that of 1962.

Monitoring of sea level has continued on an almost uninterrupted basis since June 1990. Sea level data are extracted on a half hourly interval. Reports of sea levels are forwarded to the TOGA centre in Hawaii. During the time of records the data have been found to be consistent with other stations in the Pacific. The period was strongly influenced by the El Nino phenomenon which also drastically altered the weather pattern in the Pacific Ocean.

Tides in the Tongan waters are semi-diurnal, with an amplitude of around one metre. Astronomical highest and lowest tides are separated by about 1.7 metres. Wind effects are most pronounced on the tidal record. The sea tends to build up on the windward side of the island and fall on the leeward. This effect in noticed after days of steady wind from one direction and is seen in a rise of 0.2 metres, or so.

Often in the tidal record there is a long period wave of about 50 minutes which may possibly related to the distance across the Pacific to the South American continent.

The other influence on the tidal record is the inverse barometric effect. Diurnal oscillations of one or two millibars cause a negligible effect in the tide level, but larger fluctuations during the passage of low pressure troughs cause movement of the water level by up to 0.1 metres. This in turn has an influence on groundwater levels.

In 1993 a new and highly accurate tide gauge will be installed at the Queen Salote Wharf as part of the monitoring of sea level change in the Pacific by the National Tidal Facility in Australia.

5. GEOLOGY AND SOILS

5.1 Regional setting

The Kingdom of Tonga lies at the easternmost edge of the Australia-India Plate and is an oceanic arc that has formed in response to subduction of the Pacific Plate over a period of at least 45 million years (Gatliff, 1990). The regional setting is best illustrated by a bathymetric map of the area (Fig. 5.1a) This shows the dominant morphological features.

From east to west there is the Southwest Pacific Basin, (Fig. 5.1b) the Tonga Trench, the Tonga Ridge containing most of the Tongan Islands, the Tofua Volcanic Arc, the Tofua Trench, the Lau Basin and the Lau Ridge. The Tonga Trench is the site where the westward moving Pacific plate is subducted beneath the Australia-India Plate.

The Tonga Ridge is a massive NE-SW trending and mostly submerged mountain range (Scholl, Vallier and Maung, 1985). It rises above the Tonga Trench from depths of 10,500 metres to the marginal oceanic sea of the Lau Basin (2,000 to 3,000 metres).

The principal Tongan islands of Vava'u, Ha'apai, Nomuka and Tongatapu Groups are elevated masses of Tertiary limestone and volcanic rock capped by Quaternary limestone, which rise above a central platform area. The volcanic islands and seamounts of the Tofua Arc rise from a separate, mostly submerged cordillera to the west of the crestal area of the Tonga Ridge. The Tofua Trough, a depression of about 1,800 metres, separates the Tofua Volcanic Arc from the crestal area of the Tonga Ridge.

The Tofua Volcanic Arc is a younger chain which extends from Tafahi in the North-East to 'Ata in the South-West. The volcanic rocks found on these islands belong to the low-potassium island arc tholeiites. (Cunningham and Anscombe, 1985). Basaltic andesite is the dominant rock type except on Fonualei where dacite predominates.

The bathymetry of the Tonga Ridge shows a division into a series of blocks varying from 25 to over 150 km in length. The origin of these has been related to differential uplift associated with subduction of Pacific Plate seamounts, the location of faults, the boundaries of sections of the arc with different tectonic histories and the location of blocks which have rotated in response to oblique subduction.

The oldest rocks found in Tonga are the island arc tholeiites which were uplifted and eroded prior to the deposition of shallow-water, tropical, mid to Late Eocene limestones. These are only exposed on 'Eua where they are unconformably overlain by a sequence of Miocene volcanoclastics and thin micritic limestones. A series of Pleistocene coral limestone terraces unconformably cap the older rocks.

Similar limestone terraces are the only exposed rocks on the Vava'u, Ha'apai Groups and the island of Tongatapu.

BATHYMETRY OF TONGA

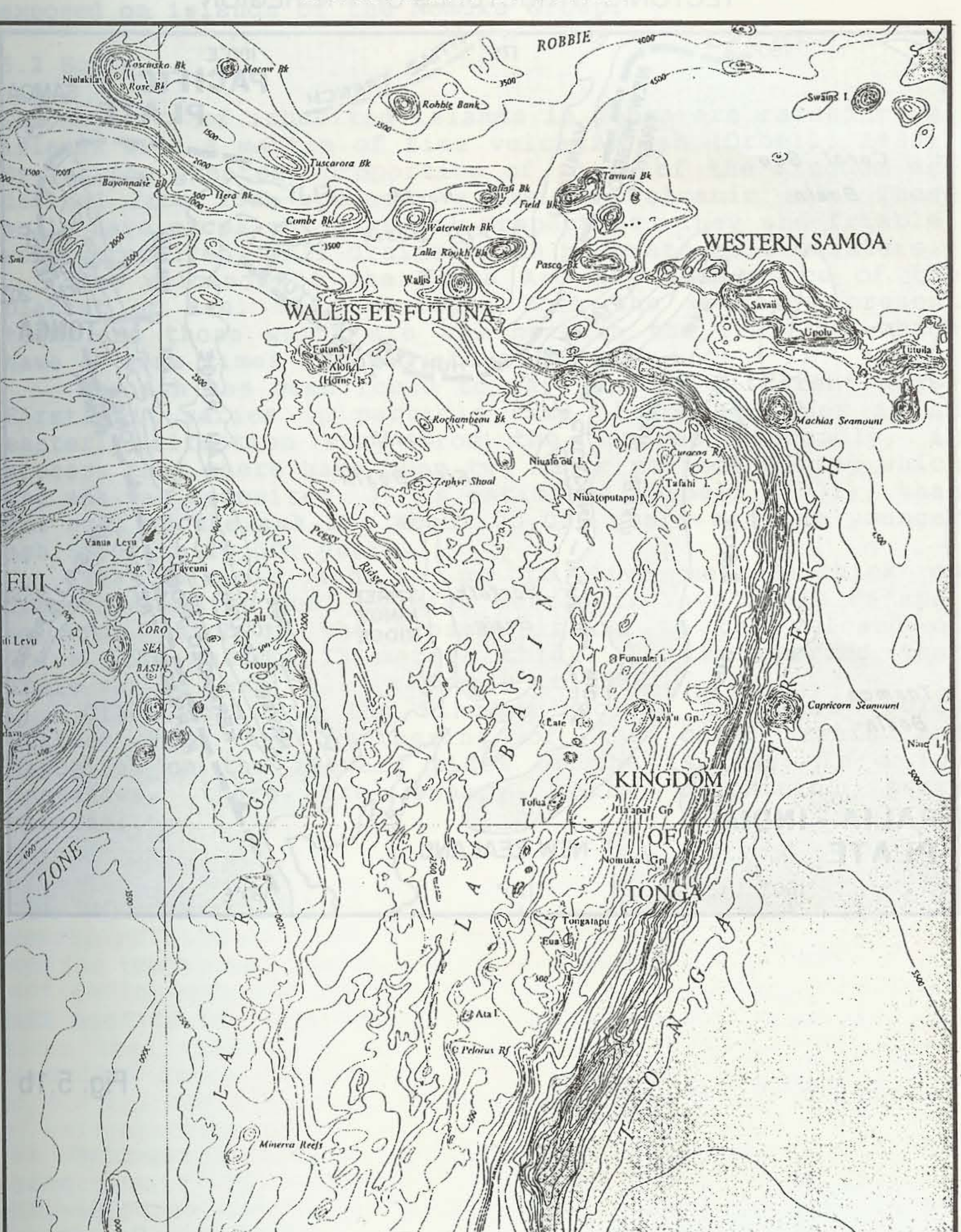


Fig. 5.1a

TECTONIC STRUCTURES OF THE REGION

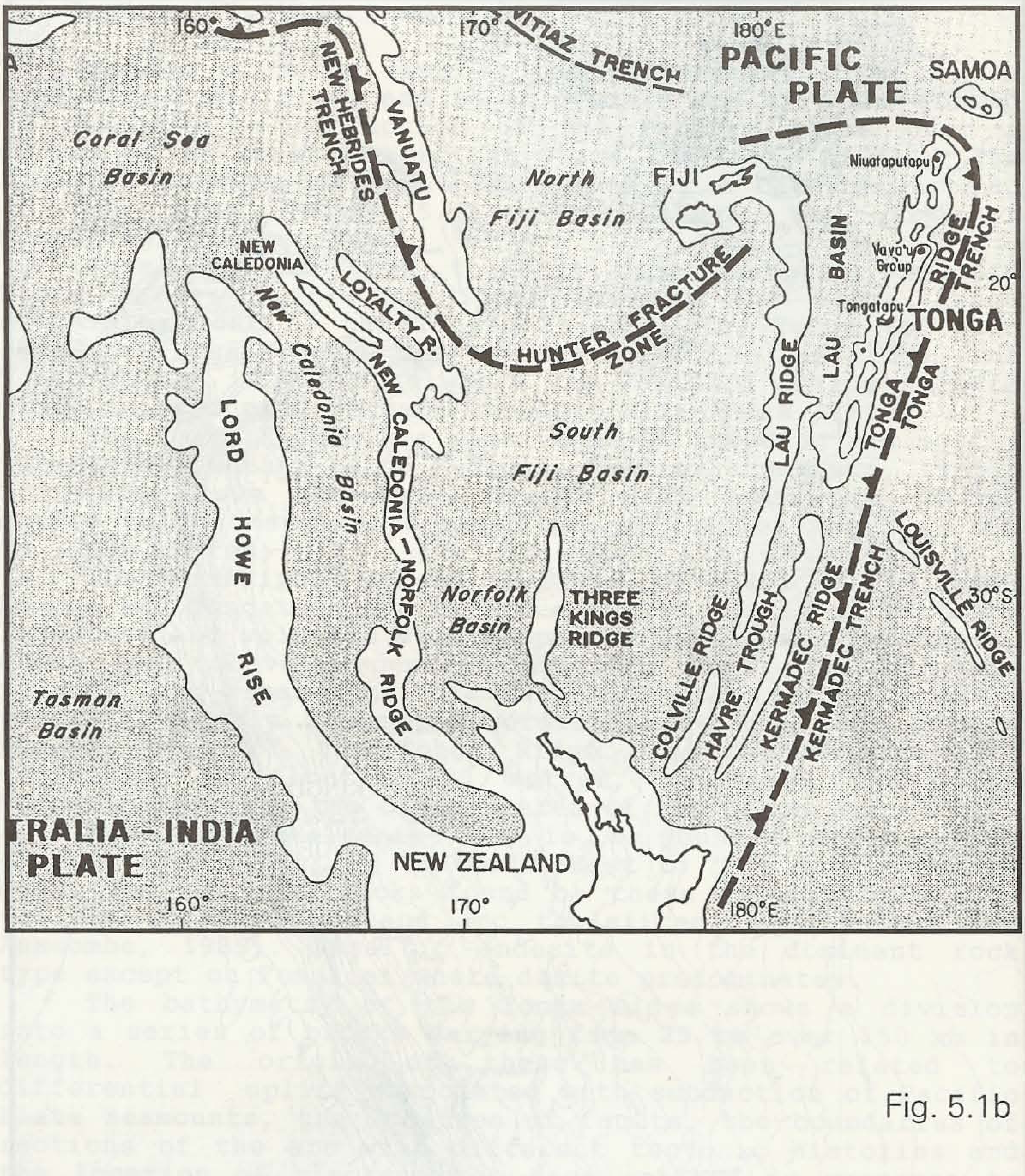


Fig. 5.1b

Miocene volcaniclastics and calcareous mudstones are exposed on islands of the Nomuka Group.

5.2 Soils

The majority of inhabited islands in Tonga are raised coral islands with a mantle of fine volcanic ash (Orbell, 1983). By far the greatest proportion of soils of the Kingdom are derived from fine-grained, andesitic volcanic ash. These soils have excellent physical properties. They are friable, well structured, well drained with moderate soil moisture.

The volcanos of the Tofua Arc are the source of the blanket of ash. This includes both the volcanos present today and those which are now beneath the sea, but which have at some times erupted above the sea.

The ash has been found to vary in two different ways. Firstly it varies in particle size, becoming finer in an easterly direction away from the sources. Secondly, it appears that there have been two major periods during which the ash was deposited. It is estimated (Orbell, 1971), that the ages of the ash are about 20,000 years and the younger ash 5,000 to 10,000 years.

The volcanic ash is up to five metres thick on Tongatapu and as much as nine metres in Vava'u. In Ha'apai on Kotu, which is the closest island to the volcano of Tofua, the ash is 13 metres thick. It is reported that there was an ash fall in Vava'u in 1886.

Other soils in the Kingdom include the sandy soils derived from the weathering of the coral reefs and deposited on the leeward sides of the islands. In a few instances, there are swampy soils containing peaty material.

6.0 HYDROGEOLOGY

6.1 Introduction

The hydrogeology of the Kingdom of Tonga has been briefly examined by a number of authors from the 1970's until the present. The current study has involved three years of investigation and monitoring. The study has included visits to almost all of the inhabited islands of the Kingdom and a few uninhabited ones. While many of the inspections have been brief, there is sufficient information to make a hydrogeological description of each island.

6.1.1 Hydrological Cycle in Tonga

The hydrogeology of Tonga can be generalized by considering the Hydrological Cycle and it's influence on small islands. Small islands are defined as having an area not greater than 2,000 km^2 or where the width of the island is less than 10 km (Falkland, 1991b). Most of the islands fall into the category of "very small islands" with an area not greater than 100 km^2 or a width not greater than three km (Dijon, 1984). The very small island category includes small volcanic and raised coral islands of the Pacific Ocean where surface water does not exist in an exploitable form and fresh groundwater resources are limited.

The input into the Hydrological Cycle of the islands is convectional rainfall from a warm moist maritime environment. Orographic effects are limited to a few of the islands which are either high raised coral or volcanic. On the coral islands, the permeability of the soils and underlying coral is so high that infiltration is rapid and precludes the existence of perched surface water bodies with only a few exceptions.

Storage of water on coral and sand islands is in the form of a fresh water lens beneath the island. The lenses are generally thin with a thick transition zone to the underlying sea water. Discharge may be observed along the beaches and lagoon in the form of springs and through the formation of beach rock.

6.2 Previous investigations

The hydrogeology of the country is first reported in Pfeiffer (1971) and Pfeiffer & Stach (1972) and only concerns Tongatapu. D. Pfeiffer was engaged in hydrogeologic investigations on the island of Tongatapu from 17 February to 3 March 1971. A detailed inventory of existing springs and wells was prepared to determine the existing capacity for use of groundwater and whether greater demands for groundwater could be met in the future without causing salt water intrusion of the shallow limestone aquifer.

Observations were made in 46 wells. A survey of the groundwater table was made and a contour map of Tongatapu prepared for February 1971. The water level was found to be mostly less than 0.6 metres above sea level.

Water samples were taken from 32 wells and the chloride contents assessed. The range was from 30 to 558 mg/l. It was noted that comparison with values from 1959 and 1965 showed an increase in chloride content. Total hardness was analysed in a few wells and found to be 300 mg/l.

A water analysis of the Nuku'alofa water supply was made on 15th February 1971. The results are shown below;

ph		7.2
Total Hardness		315 mg/l
Calcium Hardness		306 mg/l
Total Dissolved Solids (180^0C)		549 mg/l
Chloride		89.6 mg/l
Sulphate		23.1 mg/l
Iron		0.18 mg/l
Free ammonia	Less than	0.2 mg/l
Nitrate		5.0 mg/l
Nitrite		0.4 mg/l

Pfeiffer reported a chloride content of rainfall of seven mg/l.

Waterhouse (1974) visited Tongatapu and prepared a brief report on the condition of a cable tool drilling rig which was used to drill wells in Tonga. Three holes for testing the depth of the salt water interface were proposed at Liahona, Mu'a and Taliai (near Fua'amotu).

In 1976 additional work was carried out with the drilling of two wells and testing one at Mataki'Eua. Wells 116 and 118 were drilled. Testing of well 118 at a pumping rate of 4.5 l/s did not cause any drawdown of water level in the well. Waterhouse noted a water level fluctuation of 20mm and thought this could be a combination of drawdown and tidal fluctuation. The test only indicated that the aquifer transmissivity was extremely high.

At the time of testing the water level at well 118 was indicated to be 0.74 metres above sea level. However, the datum used then is slightly different from the currently used 1990 datum. Waterhouse suggested that a pumping rate of 3.8 l/s would have little effect on the fresh water lens at well spacings of 150 metres.

Forbes (1977) carried out a geophysical study over the western part of Tongatapu using the resistivity method. However, this was unable to provide the fresh water table or the depth to the salt water level.

Hunt (1978) carried out an analysis of the groundwater resources of Tongatapu. He used the water level and quality data reported in previous references to construct a finite difference model of the aquifer. The dispersion of the chloride ions across the fresh/salt water interface was calculated. A useful plot of the change in initial concentration of chloride content with changes in either head or recharge was provided. A change in recharge can be caused by water abstraction. Comparison of the recent data on water quality at Mataki'Eua together with the extraction rate showed that the method was acceptable for predicting changes in chloride concentration.

Lao (1978) reported on the construction of three wells drilled to test the thickness of the fresh water lens at Liahona, Kolonga and Fua'amotu on Tongatapu. A relatively uniform thickness of the freshwater lens of 16.7 metres was found at each site. The transition zone from potable water to sea water was between 3.7 and 7 metres, giving a fresh water with less than 200 mg/l of 9.1 metres at Liahona, 12.8 metres at Fua'amotu and 12.2 metres at Kolonga.

Lao estimated the volume of fresh water which could be safely used. The water chemistry was assessed for its suitability for domestic use. The net annual infiltration was calculated to be 1.14×10^8 m^3. The production figures for Mataki'Eua wellfield were presented for the period 1968 to 1978. The consumption increased from 0.25 to 2.21 Ml/d. Lao estimated that the total consumption for the whole of Tongatapu was 4.5 Ml/d in 1978. He advised that the amount of water which could be safely developed is 61.8 Ml/d. (20% of the annual recharge).

Lao notes that the survey datum used by Waterhouse was 0.3 metres too high. He recommended a program of groundwater data collection.

Waterhouse (1984) carried out a review of the water supply throughout the Kingdom. He gave production figures for the period of 1983 to 1984 for the Mataki'Eua wellfield. For June, 1984 the average daily consumption was 3.47 Ml/d. At the time of writing the number of wells at Mataki'Eua had increased to 33 and there were 6 production wells at Neiafu, Vava'u.

The water supply in Ha'apai was mentioned for the islands of Lifuka and Foa. Consumption at Pangai-Hihifo was 0.084 Ml/d. The wells on Lifuka were reported to pump salty water. The salinity was slightly better on Foa, but still exceeded WHO guidelines for chloride concentration.

Waterhouse drew attention to the dangers of using private well supplies in Ha'apai and Nuku'alofa due to the possibility of contamination. The water supply wells on Vava'u were described. There were 18 wells supplying villages of which seven were mentioned in the 1981 drilling report. Waterhouse reported on the anomaly that several of the surveyed holes had water levels below sea level. The consumption in Neiafu in 1984 was 0.043 Ml/d.

Waterhouse also discussed the water supply from the cave streams and springs on 'Eua. He pointed out the potential for contamination of the sources and the vulnerability of the surface supplies to drought conditions.

Wilkinson (1985) provided a report to the Food and Agricultural Organization of the United Nations on proposed water resources legislation. In the report the existing legislation in the Kingdom was reviewed. The laws of the Water Board Act of 1966 and the Public Health Act contained water legislation. Wilkinson found that these needed reviewing and drafted "An act to provide Authority for the Planning of Water Resources Development; the Management, Operation and Maintenance of Water Supply Works; The Regulation of Water Uses and; the Prevention and Control of Water Pollution". The Bill was subsequently rejected by the Parliament.

Lao (1985) carried out investigations on Foa and Lifuka to recommend locations and extraction rates for new wells. He measured the salinity levels in the two production wells for Pangai and Hihifo. Similar measurements were conducted on Foa and in the private wells of Koulo, Holopeka, Pangai and Hihifo on Lifuka. The response of water levels to tidal fluctuations was noted. Lao was the first person to comment on the two aquifer hypothesis on Lifuka. He recommended that salinity monitoring wells be constructed on Foa and Lifuka.

Belz (1985) produced a report on the Sanitation and Reclamation of Nuku'alofa. He recommended that drainage be considered only in areas below 0.5 metres elevation in the Nuku'alofa area. Settled areas below 0.6 metres in elevation be filled. He presented tide gauge readings in the Fanga'Uta Lagoon for three months of 1984 taken at the Peace Corps office in Ngeleia.

Dale (1987) carried out a geophysical investigation on the island of 'Uoleva in Ha'apai. This was essentially a training exercise on an uninhabited sand island. It located a weakly developed fresh water lens.

Stoll (1987) reported on groundwater investigations on Lifuka and Foa, Ha'apai. From the recommendations of Lao (1985) four test wells were drilled on Foa and three on Lifuka. They were drilled to the salt water to measure the thickness of the freshwater lens. On Foa the test wells showed that the groundwater was mostly salty. On Lifuka well number 5 was drilled 200 metres east of Taufa'ahau College and intersected seven metres of fresh water. Well number 6 was 500 metres north of the Water Board wells and had a slightly fresh surface, directly underlain by a 12 metre thick transition zone to the sea water.

Well number 7 was drilled near Hihifo in sand and soft coral. By the time measurements of water salinity were made it had collapsed with only 0.42 metres of fresh water in the well. A test of pumping and salinity was made on the Water Board well which showed an increasing high salinity.

Kafri (1989) made an assessment of the groundwater potential of Tongatapu. He calculated the recharge rate using a single value of chloride concentration in rainfall and the freshest chloride value in groundwater. Kafri looked at the karstic features of the island and presented data on the chloride content from a number of wells.

Hasan (1989) prepared a report on the possibilities of rainwater harvesting using either collection and storage of rainwater underground at sea level, or from ground catchment using a flexible surface cover. He calculated the crop water requirement for the existing mixed cropping pattern. It showed that a 1 in 5 year rainfall does not meet the crop water requirement. There is a deficit of 163 mm during the drier months from June to November.

Warbrick (1989) carried out resistivity soundings on 'Eua. A total of 28 resistivity soundings were made on the western side of the island. The quoted accuracy of plus or minus ten metres for locating the top of the fresh water lens is totally unacceptable in an island situation.

Falkland (1991a) carried out a detailed assessment of the hydrogeology of Tonga in a water resources development volume of the Tonga Water Supply Master Plan Project. He undertook aa analysis of all the available rainfall data in the Kingdom. These were used in a model to obtain estimates of recharge for the major groups. The following recharge estimates as a portion of the mean annual rainfall were made;

Tongatapu	30% or 528 mm
Lifuka, Ha'apai	28% or 478 mm
Neiafu, Vava'u	41% or 917 mm

Falkland estimated that the current water use on Tongatapu to be 38% of the sustainable yield in the western portion and 9% for the remainder of the island. The total sustainable yield was conservatively estimated to be 52 Ml/day.

6.1.3 Current investigation

A study of the groundwater resources and water supply was carried out for this report from 1990 to 1992. The methods employed included a review of the literature, hydrogeological observations, well census, water sampling, test drilling, geophysical methods, surveying, sea level and lagoon level monitoring, well hydrographs, air photograph interpretation, modelling, climate monitoring and test pumping.

The data collected in this study have been used to prepare a hydrogeological map and a description of the hydrogeology, water supply and suggested improvements for each of the inhabited islands. For simplification into the Tongan recognition of island groups, the data are presented in each of their respective groupings, from the south of the country to the north.

For consistency of presentation, the maps are presented at two scales. This is to allow the smallest of islands to be presented at a reasonable size and yet to allow the largest islands to be shown in detail without cramping the illustration. It was tempting to use variable scales to allow each island to fill the page, but this would have distorted the readers impression of the size of some of the smallest islands. It is important that this is not done, as the size of the island dictates whether or not fresh groundwater exists in the form of lens and to what extent the lens can be utilised.

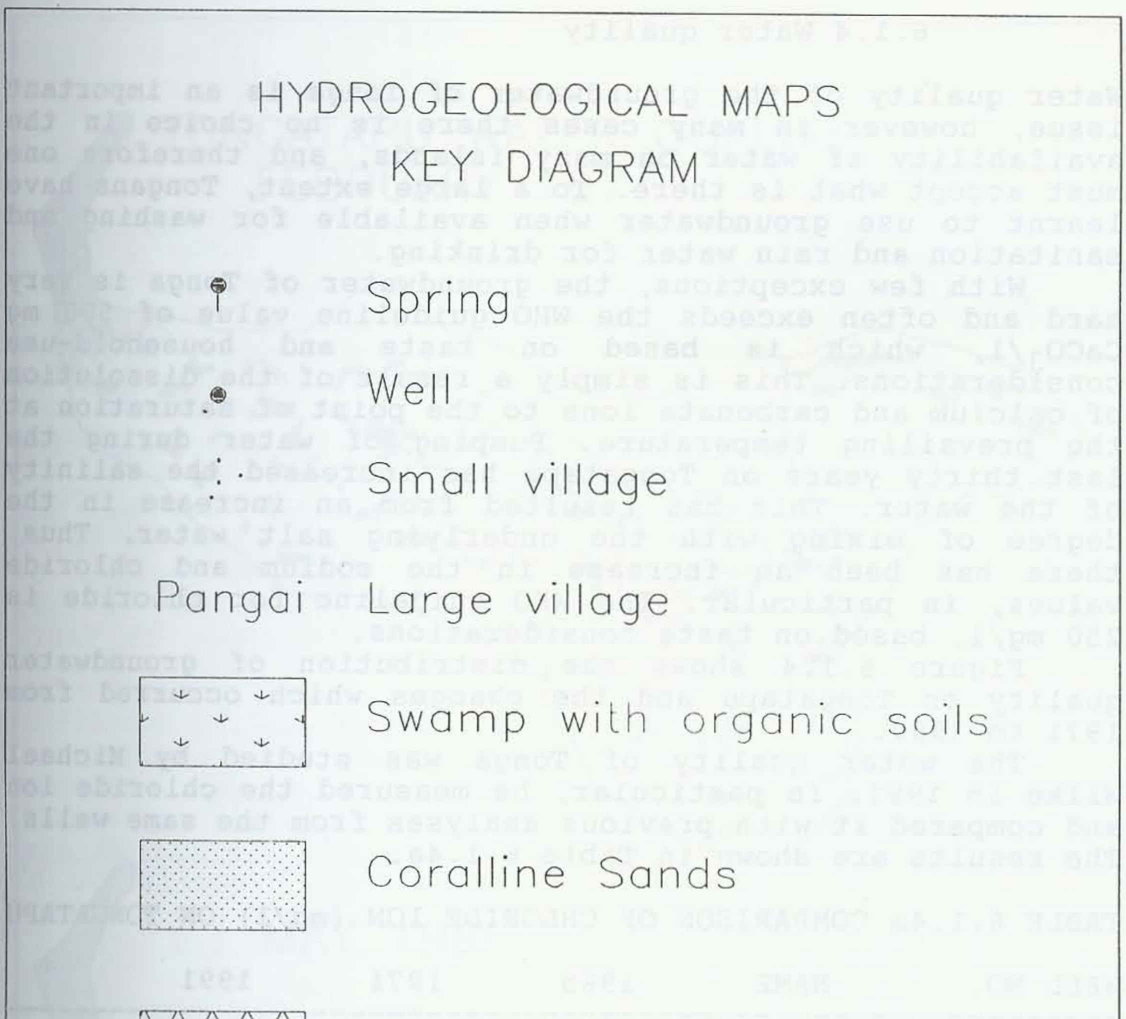

HYDROGEOLOGICAL MAPS
KEY DIAGRAM
Spring
Well
Small village
Pangai
Large village
Swamp with organic soils
Coralline Sands
Andesitic ash
Limestone
Volcanic rocks

Fig. 6.1.3

6.1.4 Water quality

Water quality of the groundwater of Tonga is an important issue, however in many cases there is no choice in the availability of water on many islands, and therefore one must accept what is there. To a large extent, Tongans have learnt to use groundwater when available for washing and sanitation and rain water for drinking.

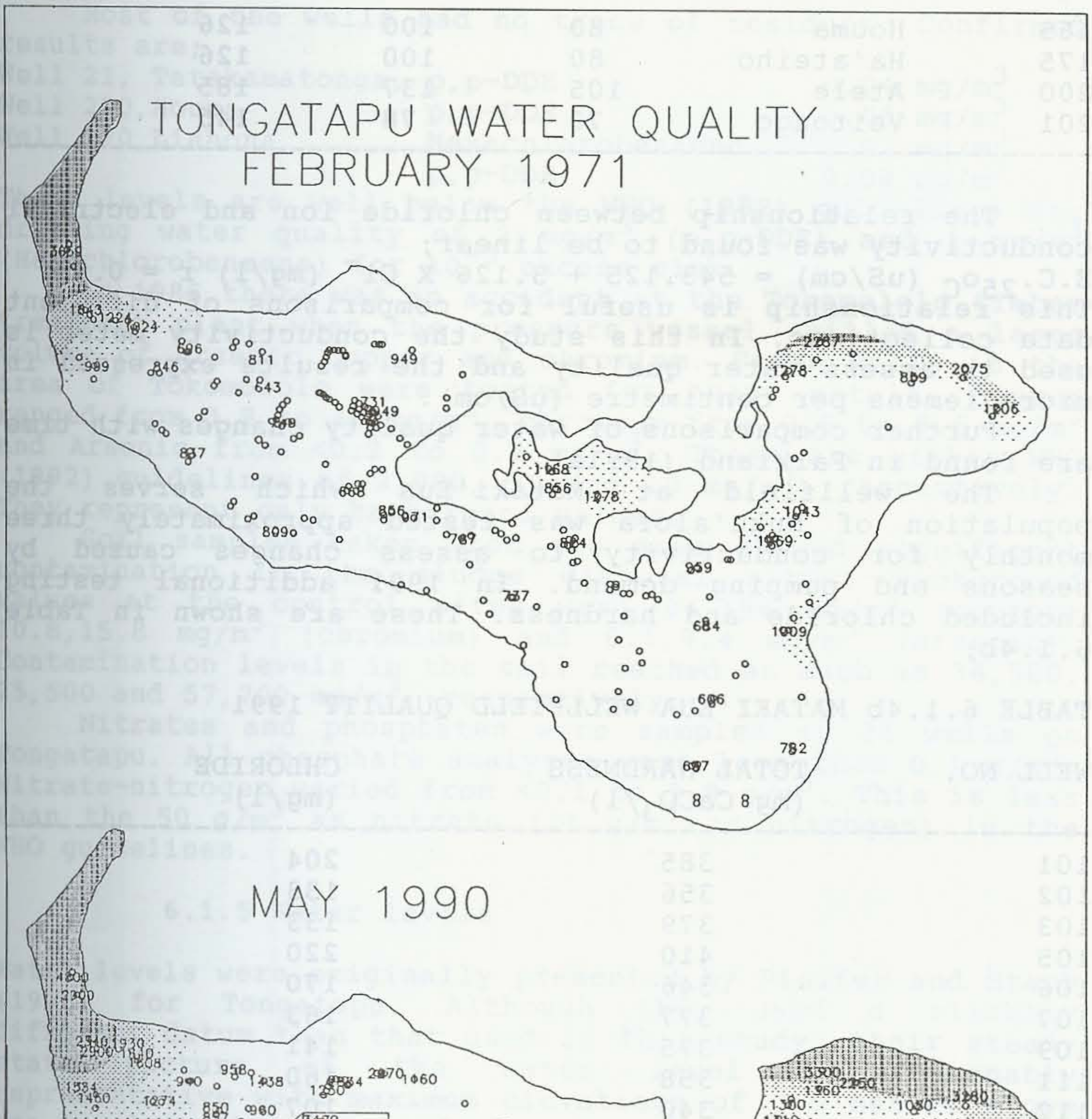
With few exceptions, the groundwater of Tonga is very hard and often exceeds the WHO guideline value of 500 mg $CaCO_3$/l, which is based on taste and household-use considerations. This is simply a result of the dissolution of calcium and carbonate ions to the point of saturation at the prevailing temperature. Pumping of water during the last thirty years on Tongatapu has increased the salinity of the water. This has resulted from an increase in the degree of mixing with the underlying salt water. Thus, there has been an increase in the sodium and chloride values, in particular. The WHO guideline for chloride is 250 mg/l, based on taste considerations.

Figure 6.1.4 shows the distribution of groundwater quality on Tongatapu and the changes which occurred from 1971 to 1990.

The water quality of Tonga was studied by Michael Wilke in 1991. In particular, he measured the chloride ion and compared it with previous analyses from the same wells. The results are shown in Table 6.1.4a.

TABLE 6.1.4a COMPARISON OF CHLORIDE ION (mg/l) ON TONGATAPU

WELL NO.	NAME	1965	1971	1991
9	Fu'amotu Int.	-	20	35
10	Fu'amotu	25	30	33
14	Fatumu	125	149	182
19	Tatakamotonga	220	369	429
45	'Afa	445	490	492
46	Niutoa	175	212	194
52	Navutoka	415	558	645
61	Talafo'ou	95	235	172
65	Te'ekiu	130	154	256
68	Masilamea	150	218	302
101	Mataki'Eua	50	82	204
103	Mataki'Eua	28	130	162
107	Mataki'Eua	40	100	163
109	Mataki'Eua	40	87	141
111	Mataki'Eua	36	60	122
133	Fatai	60	86	184
134	Lakepa	30	32	72
144	Nukunuku	45	49	93
147	Matahau	60	97	106
153	'Umutangata	235	416	311
155	Kolovai	700	997	702
157	Fahefa	95	146	151
161	Utulau	80	85	126


TONGATAPU WATER QUALITY
FEBRUARY 1971
MAY 1990
Mataki'Eua
Tongamai
CONDUCTIVITY uS/cm
500 - 1000
1000 - 1500
1500 - 2000
>2000
N
0 km 5
Fig. 6.1.4

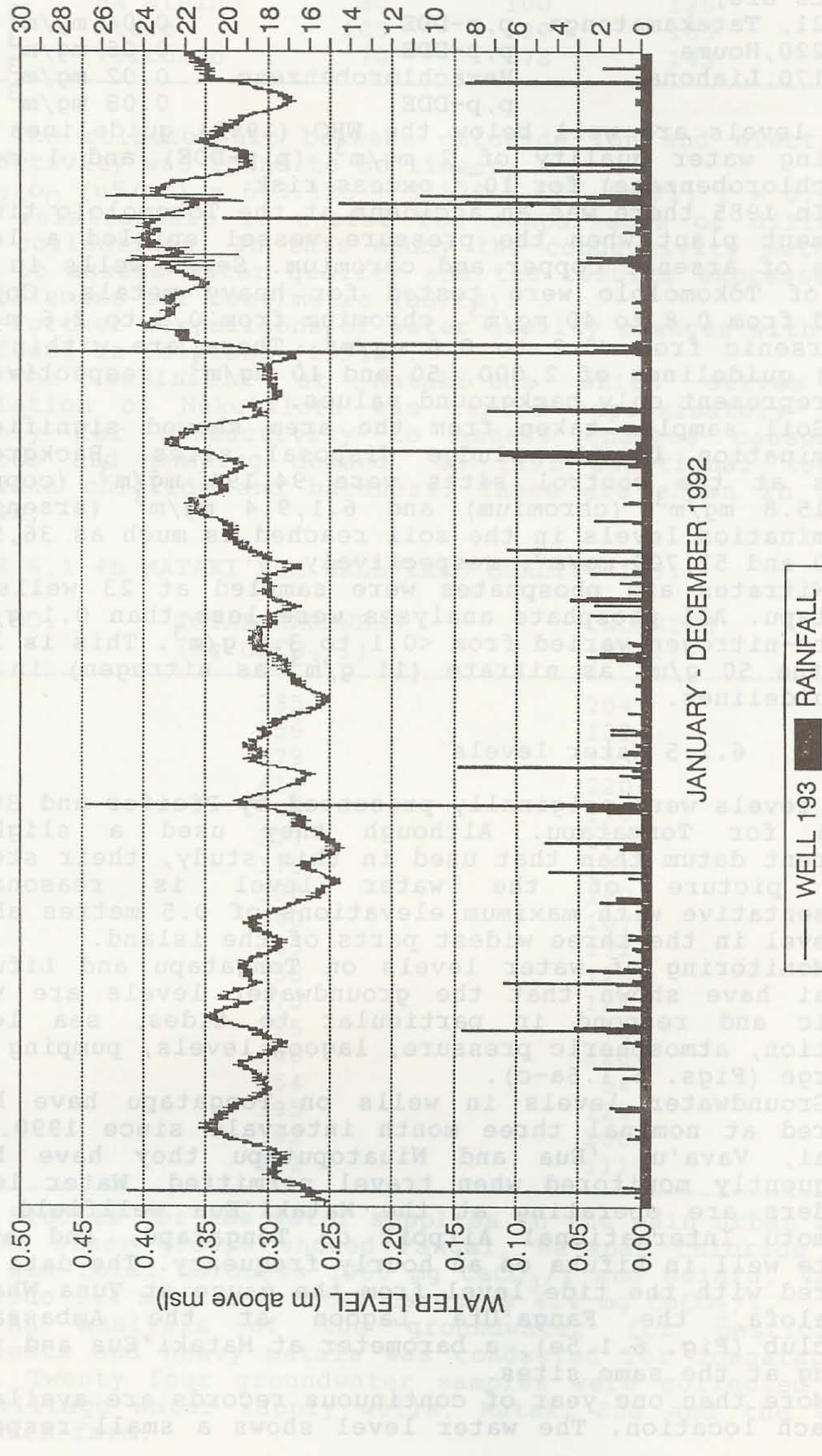

HYDROGRAPH WELL 193, TONGATAPU
WATER LEVEL (m above msl)
HOURLY RAINFALL (mm)
JANUARY - DECEMBER 1992
WELL 193
RAINFALL

Fig. 6.1.5a

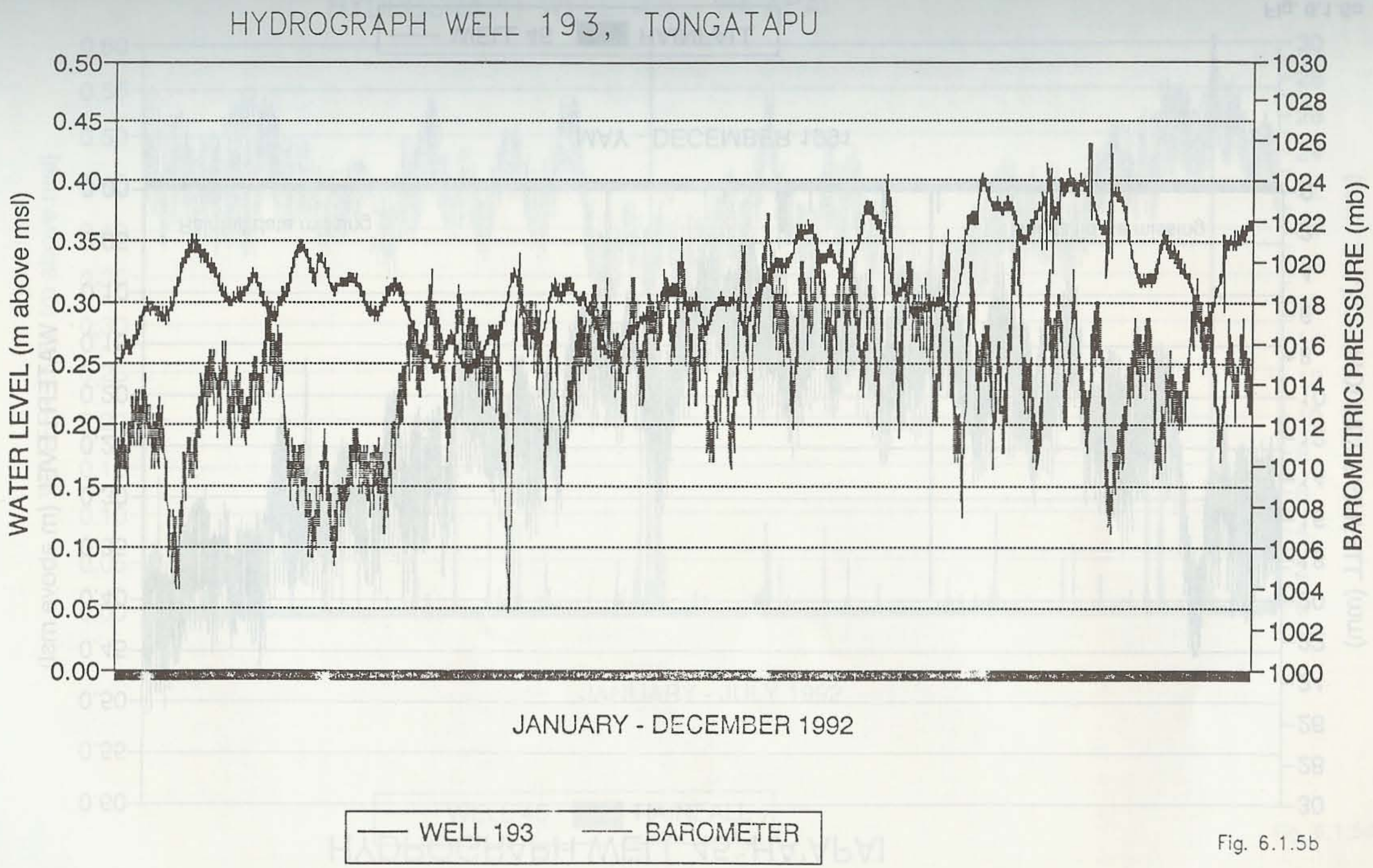

HYDROGRAPH WELL 193, TONGATAPU
WATER LEVEL (m above msl)
BAROMETRIC PRESSURE (mb)
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
1030
1028
1026
1024
1022
1020
1018
1016
1014
1012
1010
1008
1006
1004
1002
1000
JANUARY - DECEMBER 1992
WELL 193
BAROMETER

Fig. 6.1.5b

to tides, even at the centre of Tongatapu (Fig.6.1.5a), more so in Ha'apai (Fig.6.1.5c-d). Superimposed on the tidal pattern is a longer period inverse barometric effect (Fig. 6.1.5b). This is of larger magnitude than the tidal pattern. On subtracting the two influences from the hydrograph, the remainder is the recharge from rainfall events.

The years of 1991 and 1992 were not particularly good for observing the recharge to the fresh water lens. This was due to a period of eight continuous months of below-average rainfall attributed to the El Nino effect. In fact, it was a good period for calibrating the effects of tide and pressure on the water level without recharge. In following years it should be possible to quantify the percentage of rainfall which recharges the fresh water lens.

Fluctuation of the water level in 1991 to 1992 was as much as 0.3 metres on Tongatapu and Lifuka (Figs 6.1.5a-c). This is about 50% of the steady state level presented by Pfeifer and Stach (1972) and highlights the need to consider the fresh water lens in dynamic terms.

In Ha'apai there was almost a complete collapse of the water level to within 0.05 metres of mean sea level before recharge restored the level to its former 0.3 metres above mean sea level (Fig. 6.1.5b).

It was surprising to see on Tongatapu falls of 0.3 metres in the fresh water level without a drastic change in the conductivity of the water. Generally a rise of about 10% was noted in monitoring. It is concluded from this evidence that the movement of the transition zone from fresh to salty water is damped.

The water level of Fanga'Uta Lagoon influences the local groundwater levels and discharge. The level is primarily affected by the tide, but in addition rainfall and wind pattern have a strong effect. The peaks in lagoon level coincide with heavy rainfall (Fig. 6.1.5e).

6.1.6 Water supply

The history of groundwater development is as old as the Tongan civilization (Lao, 1978). Island cultures in the Pacific normally resorted to the use of shoreline springs and streams. It is assumed that caves such as 'Anahulu at Haveluliku with a pool of fresh water were used.

There is a Tongan legend which describes the origin of five wells in Ha'apai and one in Vava'u. It relates to the travelling of a Samoan princess to Tongatapu and the efforts of the devil to trick her into giving him some water. This is thought to imply that the Samoans taught the Tongans the art of finding underground water (Helu, pers. comm.)

Ancient Tongan water wells or vaitupu are seen in low-lying coastal areas. They consist of a conical excavation in the soil down to the water table. Several good examples can be seen in the Tokomololo area on Tongatapu. Such wells would have served as centres of water supply for centuries. When the population settled into towns, the digging of shallow wells on individual alotments probably commenced.

In 1909 a beginning was made on the construction of large concrete water cisterns in the villages, to give people an abundant supply of clean, disease-free rain water. These tanks were the first and perhaps most significant development in public health after the quarantine laws and before mass vaccination (Campbell, 1992). They represent King Tupou II's most lasting achievement.

In 1924 the Rockerfeller Foundation funded a project which included the provision of a safe uncontaminated water supply. Collecting sufficient water to keep the cisterns filled was a problem, until about 1930 when the people overcame their extreme reverence for the house of God, and accepted that rain water from the church roofs was not tapu.

By 1946 community tanks had been established in most villages and approval was given for a reticulated water supply for Nuku'alofa. However, it was many years before this came to pass. Diseases such as enteric fever were brought under control in 1951 by mass inoculation but could not be entirely eradicated as long as people continued to use contaminated well water.

The critical need was for water which was uncontaminated by biological wastes. Throughout the Kingdom, well water was a source of infection, and was the reason for the construction since 1909 of communal water cisterns. A more satisfactory solution would be the tapping of deep, natural reservoirs of fresh water if they existed in sufficient volume. In 1957 therefore, the government approached the United Nations for assistance, and an agreement was reached with the World Health Organisation (WHO) and the United Nations Children's Emergency Fund (UNICEF) to share the cost of an environmental sanitation program.

Towards the end of 1958 a public health engineer arrived to undertake feasibility studies. By 1961, a pilot project was completed, supplying piped water to the villages of Houma and Vaotu'u. Over the next two years the supply was extended to a further sixteen villages.

The supply of piped water to Nuku'alofa and also in Vava'u, began in 1965. The first five hand-dug wells for Nuku'alofa were constructed in 1966, another in 1968 and two more wells were added in 1971. After that time New Zealand aid provided a drilling rig from DSIR which constructed village wells in Tongatapu and Vava'u.

Australian aid programs have provided financing for the drilling and equipping of 11 wells on Tongatapu. Under the small grants scheme a continuous program of upgrading water supplies using drilled wells, pumps and storage tanks where the groundwater availability permits. Elsewhere there have been programs of construction of cement water tanks for individual houses.

New Zealand aid has provided 25 fibre glass tanks in Tafahi and also on Niua Fo'ou. Australian aid has provided numerous fibre glass and cement tanks for village water supply on Tongatapu and in Ha'apai. Fifty individual fibre glass tanks were installed in 1992 in Fangale'ounga, Ha'apai.

In 1990 and 1991 work was carried out on the Tonga Water Supply Master Plan Project (PPK Consultants in association with Riedel & Byrne, 1992). The purpose was to assist in improving health, living conditions and economic opportunities, through the provision of adequate, safe and reliable water supplies. This was done by the preparation of Master Plans for the staged upgrading and expansion of existing water supply systems to accommodate predicted changes in water demands over the twenty year period from 1991 to 2011.

Master plans were prepared for Nuku'alofa, 'Eua, Neiafu, Lifuka, Vaini, Mu'a, Houma, Te'ekiu, Haveluliku, 'Uiha, Longomapu, Tu'anuku, Felemea, Niua Fo'ou and Niua Toputapu. With the master plans additional reports are included on; Institutional Strengthening and Community Component, Proposed Water Resources and Water Supply Legislation and the Water Resources Development Master Plan.

6.2. Tongatapu Group

6.2.1 Description

The Tongatapu Group consists of the two main islands of Tongatapu and 'Eua, separated by the 'Eua channel. Smaller islands located on the northern side of Tongatapu include 'Euaiki, 'Atata, Fafa, Pangaimotu, 'Oneata and Makaha'a. Several of these have small tourist resort facilities.

6.2.2 Tongatapu

Tongatapu is a raised coral island which reaches a maximum elevation of 65 meters at Nakolo on the south-east side and is tilted down to the low-lying north coast. The youngest rocks exposed on Tongatapu are Pliocene and Pleistocene limestone with a known thickness of up to 247 metres. This reefal body lies above approximately 2,400 metres of upper Eocene to lower Pliocene volcaniclastic, tuff, and lava beds.

Tongatapu is believed to have formed initially as a reef on the south-east of the present island and to have been progressively uplifted with new reef formation on the leeward (north-west) side. As a consequence there are the topographic features we see today. These include the cliffs on the south-eastern side, the shallow lagoon in the centre, the deposition of sand and swampy material around

6.2 Tongatapu Group

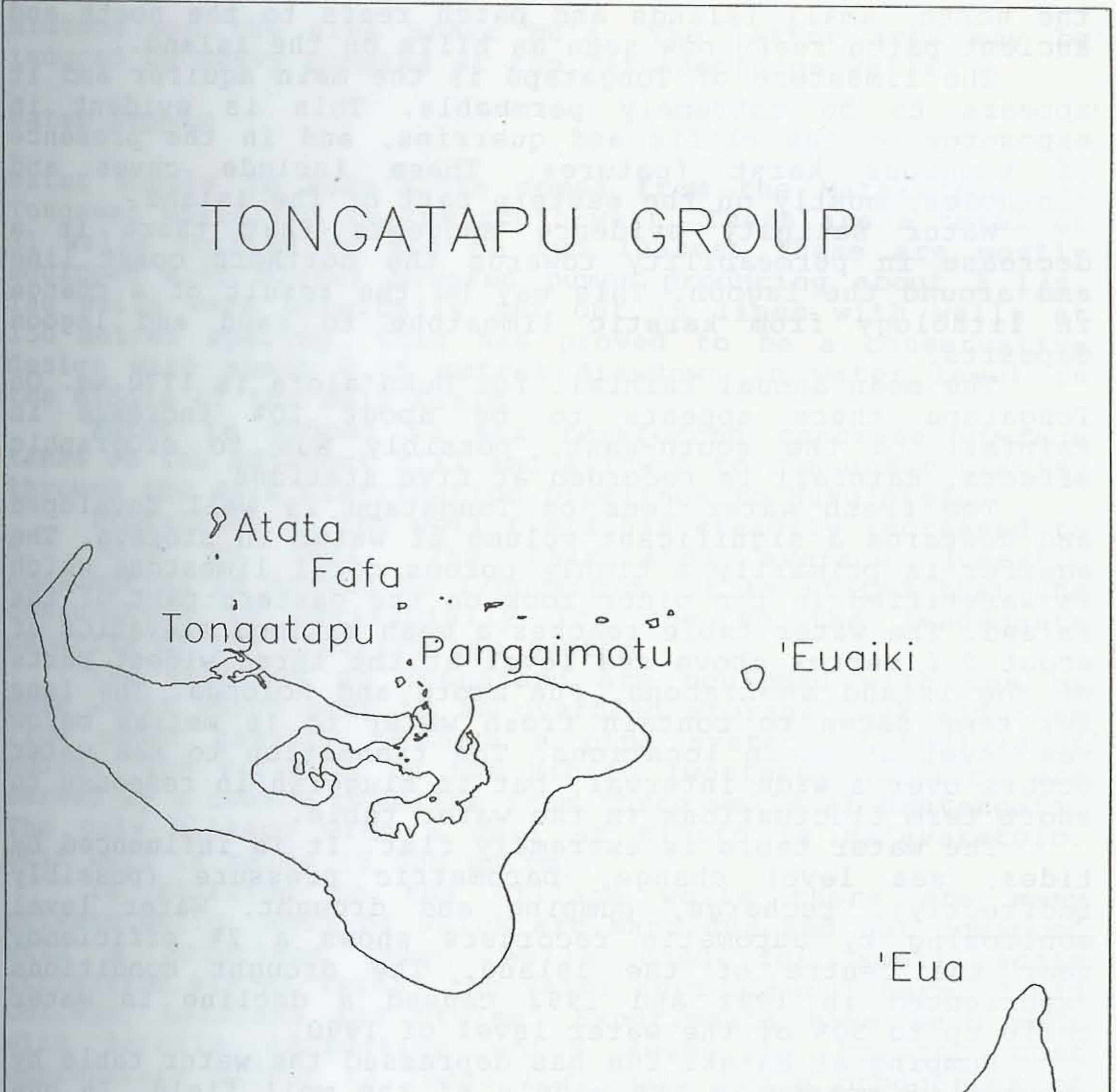

TONGATAPU GROUP
Atata
Fafa
Tongatapu
Pangaimotu
'Euaiki
'Eua

Fig. 6.2.1

the north, small islands and patch reefs to the north and ancient patch reefs now seen as hills on the island.

The limestone of Tongatapu is the main aquifer and it appears to be extremely permeable. This is evident in exposures on the cliffs and quarries, and in the presence of numerous karst features. These include caves and sinkholes, mostly on the eastern part of the island.

Water salinity evidence suggests that there is a decrease in permeability towards the northern coast line and around the lagoon. This may be the result of a change in lithology from karstic limestone to sand and lagoon deposits.

The mean annual rainfall for Nuku'alofa is 1770 mm. On Tongatapu there appears to be about 10% increase in rainfall to the south-east, possibly due to orographic effects. Rainfall is recorded at five stations.

The fresh water lens on Tongatapu is well developed and contains a significant volume of water in storage. The aquifer is primarily a highly porous coral limestone which is karstified in the older rock on the eastern part of the island. The water table reaches a mean maximum elevation of about 0.6 metres above sea level at the three widest parts of the island at Liahona, Fua'amotu and Kolonga. The lens has been shown to contain fresh water to 16 metres below sea level at those locations. The transition to sea water occurs over a wide interval, but is sluggish in response to short term fluctuations in the water table.

The water table is extremely flat. It is influenced by tides, sea level change, barometric pressure (possibly indirectly), recharge, pumping and drought. Water level monitoring by automatic recorders shows a 2% efficiency near the centre of the island. The drought conditions experienced in 1991 and 1992 caused a decline in water table up to 50% of the water level of 1990.

Pumping at Mataki'Eua has depressed the water table by about 0.25 metres in the middle of the well field. In one individual well which is monitored (105), the water level falls about 0.1 metres when the pump is operating. The conductivity of the water is inversely proportional to the height of the water table. The relationship has a low correlation and conductivity is mostly affected by the time since the last heavy rain.

Water quality across Tongatapu was examined by carrying out well sampling and preparing a map of conductivity. The map revealed that the greater part of Tongatapu has a conductivity of around 1000 uS/cm (Fig. 6.1.4). There are several parts of Tongatapu which have natural high salinities in the groundwater close to the sea. Discharge of water to the Fanga'Uta Lagoon shows mixing with underlying salt water at Vaikopuna (3,780 uS/cm) and Tufumahina (9,940 uS/cm).

Areas of high groundwater salinity include the western peninsular from Fo'ui to the north-west tip, the liku coastline from Veitongoliku to Haveluliku, the Folaha peninsula, the north east coastal flats from Navutoka to

Niutoua and the area under Mu'a. The latter area may be induced by heavy pumping at the Tatakamotonga wells.

Water Supply

Water supply to Nuku'alofa comes from the Mataki'Eua and Tongamai wellfield to the south-west. There are a total of 31 wells drilled or dug on two leases. These are mostly equipped with diesel powered pumps producing about 3 l/s. The wells were originally set out in lines with wells at 150 metres spacing. This has proved to be a conservative design with about 0.25 metres drawdown in water level in the middle of the well field.

Water is pumped to six reinforced concrete storage tanks on the adjacent hill and allowed to run under gravity through the main distribution pipelines to Nuku'alofa.

Production of the well field has steadily increased to 5.1 Ml/d in 1991. The calculated average domestic consumption is around 90 l/person/d. It is stated that the consumption is artificially low due to the inadequate capacity of the distribution system.

The villages on Tongatapu are equipped with one or more wells which pump to an overhead storage tank and then flow under gravity through a pipe system to individual houses. The villages in the Hihifo (western) district are served by a common pipeline from three wells at Umutangata. The only village with a well at Hihifo is Ha'avakatolo. That well is salty (3,000 uS/cm).

In addition to the village wells there are many private wells, most of which are hand dug and not equipped with a motorised pump. Wells used for small scale irrigation are at Vaini, the Vaini agricultural farm, Piula College, Lafalafa and Utulau. Experiments have been made with trickle irrigation which seems to be the most appropriate method in Tonga for small scale production of vegetable crops.

Improvements

Improvements to the water supplies of Tongatapu are outlined in various reports of the Tonga Water Supply Master Plan Project (PPK Consultants in association with Riedel & Byrne, 1992).

Simple modelling studies have indicated that additional water supplies can be obtained from the western part of Tongatapu for Nuku'alofa. It appears that the supply can be increased from the present 5.3 Ml/d to about 19 Ml/d. However, the number of wells needs to be substantially increased and the wells spread over a much wider area than at present. The results of modelling need to be progressively upgraded with water quality monitoring, on a regular basis.

Water supplies beyond 19 Ml/d will have to come from the eastern side of the island. The largest source of water is in the area of Fua'amotu airport which is currently used only for several villages. It is likely that an additional 20 Ml/d could be obtained from that area in the future.

Water supplies to the villages need little upgrading in terms of the number of wells. Mostly the storage capacity and pipelines need renovating. The greatest need is for improving the management of the village water supply committees. In some villages it is apparent that the water supply administration should be handed over to the Tonga Water Board.

with a pump to supply all of 'Ohonua and the small village of Ta'anga.

The well at Kolomaile experienced drilling difficulties in several caves and did not intersect perched water. It is now thought that the volcaniclastic layer is down thrown by a fault along the scarp where the caves emerge.

In 1992, in response to the severe drought affecting the country and in particular the water supplies of 'Eua, two additional wells were drilled at Ha'atu'a and Houma. The well at Ha'atu'a was drilled between the village and the west coast at an elevation of 65 metres above sea level. The fresh water lens was intersected close to sea level. The well was equipped with a pump and during operation the conductivity of the water was 2300 uS/cm.

The water is pumped to Vaitaki to an elevated header tank. From there it is gravity fed into the pipeline from the cave sources. Upon mixing with the very fresh water the final quality is quite acceptable.

At Houma a well was drilled along the main road to the fresh water lens. The water conductivity at that site was 1400 uS/cm. The well has yet to be equipped with a pump.

Stream gauging was carried out in 1992 at two sites on Fern Gully stream and the stream issuing from 'Anapekepeka. V-notch weirs were installed and a water level recorder placed on the 'Anapekepeka stream together with a rain gauge. The manually read gauge on Fern Gully became dry in May 1992 as the total flow was diverted to the village water supply.

On 'Anapekepeka stream the flow diminished to a trickle of about 0.1 l/s for several months. The contribution from Matavai completely dried up and most of the water from the caves was used by the villages. The stream gauge record showed a diurnal pattern which was inverse to the demand on diverted water. Peak stream flow was at night with a minimum during the day.

Improvements

Improvements to the water supply are outlined in the water supply master plan. The intention is to treat the surface water sources and to supplement them with groundwater during low flow periods.

The wells constructed in 1990 and 1992 have significantly improved the situation on 'Eua during droughts. Additional wells are required to completely supplement the cave water. These should be drilled at an approximate elevation of 60 to 70 metres above sea level in the vicinity of the airport.

DIVISION		ISLAND
TONGATAPU		TONGATAPU
LATITUDE		LONGITUDE
21° 08'S		175° 12'W
AREA	COASTLINE	ELEVATION
260.042 km^2	144.316 km	65 m
VILLAGES	POPULATION	HOUSEHOLDS
60	63,794	9,723

Hydrogeology of Tongatapu

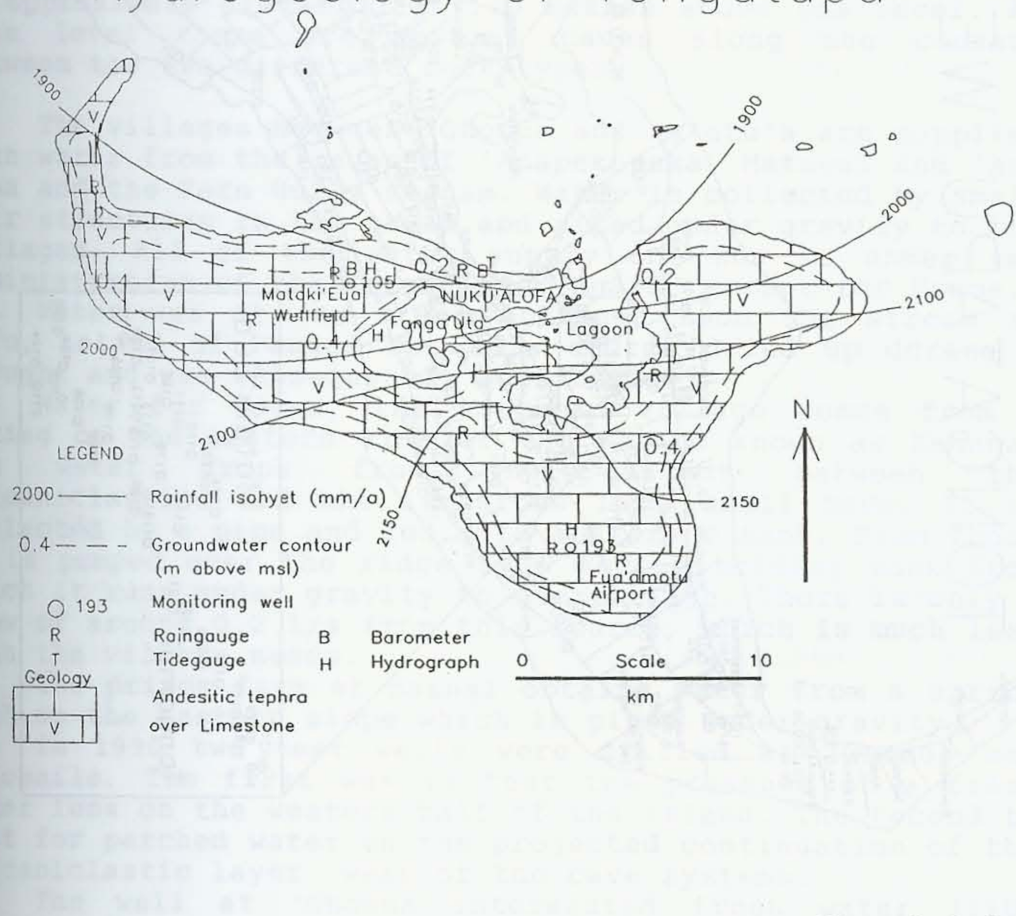


Fig. 6.2.2a

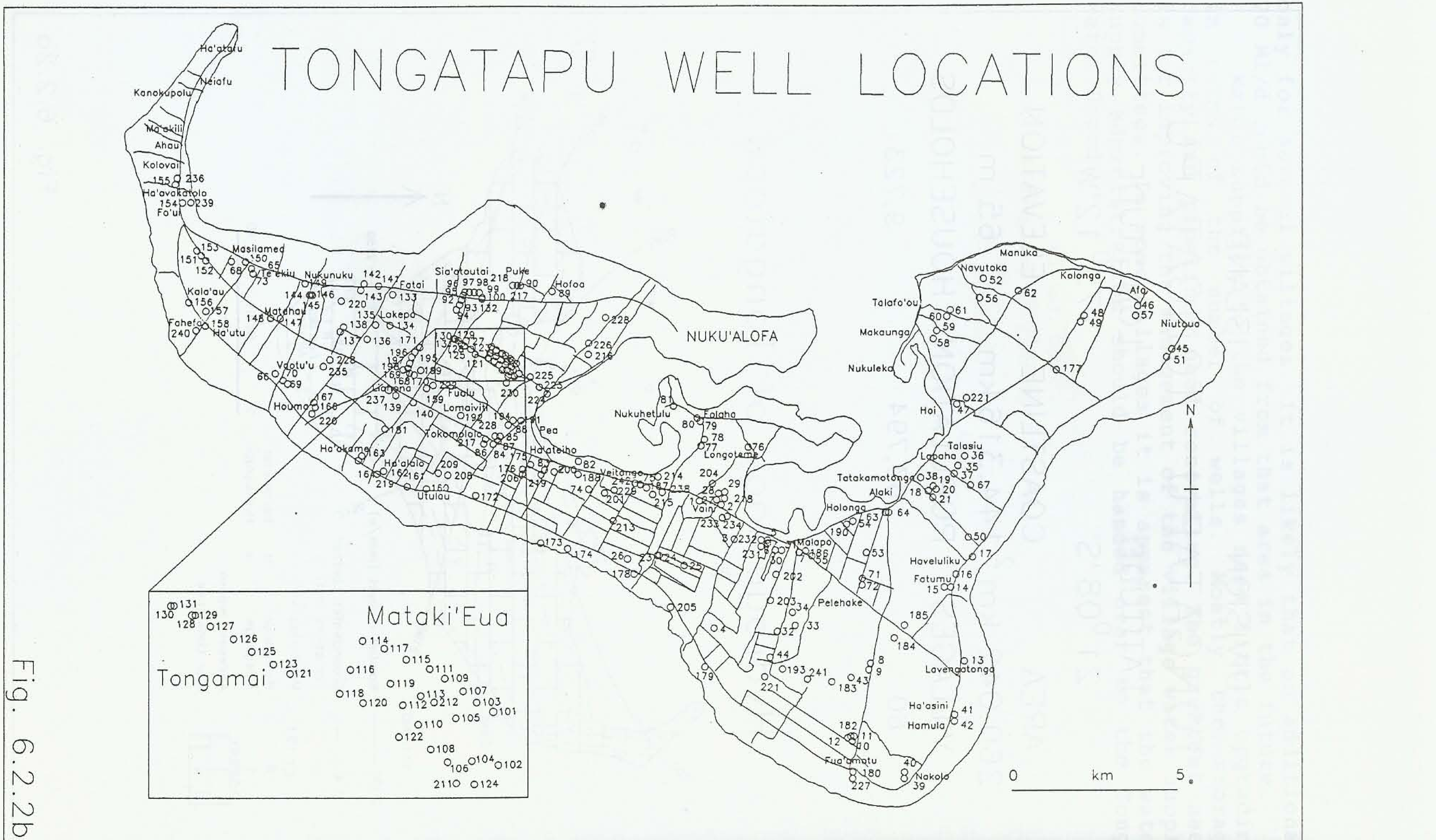

TONGATAPU WELL LOCATIONS
Ha'atafu
Neiafu
Kanokupolu
Ma'akili
Ahau
Kolovai
Ha'avakatolo
Fo'ui
Masilamea
Te'ekiu
Nukunuku
Fatai
Sia'atoutai
Puke
Hofoa
Kala'au
Matahau
Fahefa
Ha'utu
Lakepa
Vaotu'u
Houma
Fualu
Lomaiviti
Tokomololo
Ha'akame
Ha'alalo
Utulau
Pea
Ha'ateiho
Veitongo
Vaini
NUKU'ALOFA
Nukuhetulu
Folaha
Longoteme
Malapo
Pelehake
Holonga
Alaki
Tatakamotonga
Lapaha
Talasiu
Hoi
Nukuleka
Makaunga
Talafo'ou
Navutoka
Manuka
Kolonga
Afa
Niutoua
Haveluliku
Fatumu
Lavengatonga
Ha'asini
Hamula
Fua'amotu
Nakolo
Mataki'Eua
Tongamai
N
0 km 5

Fig. 6.2.2b

6.2.3 'Eua

Hydrogeology

'Eua lies to the east of Tongatapu and has the most complex geological structure of all islands in Tonga. It is elongated in a north-south direction and contains a ridge running along the major axis which reaches a maximum altitude of 312 metres above sea level.

Views of 'Eua from the west reveal the stepped structure of the island with three terraces apparent. These reflect the progressive uplift of the island. The east west asymmetry across 'Eua shows the tilting down to the west. This exposes a sequence of strata on the steep eastern cliffs. The oldest rocks exposed on 'Eua are Miocene volcaniclastics. These are overlain by Eocene limestones and volcaniclastics and Quaternary limestone.

Water Supply

The water supply on 'Eua has been the subject of several investigations. Until 1992 all of the piped water supply on 'Eua was obtained from surface water emanating from the contact between the volcaniclastics and the limestones at an approximate elevation of 120 metres above sea level. At this level there are several caves along the contact between the two different rock types.

The villages between 'Ohonua and Ha'atu'a are supplied with water from the caves of 'Anapekepeka, Matavai and 'Ana Saoa and the Fern Gully stream. Water is collected by small weir structures in the caves and piped under gravity to the villages. All of the water supply on 'Eua is under the administration of the Tonga Water Board, except for Houma.

Water was at one stage obtained from the stream at Hafu, inland of Pangai but this source dried up during a drought and was subsequently abandoned.

Water for Houma, the northern village comes from a spring on the eastern side of the island known as Kahana. The water drips from the contact between the volcaniclastics and the limestone in a small cave. It is collected by a pipe and led into a storage tank. From there it is pumped over the ridge to a second holding tank from which it runs under gravity to the village. There is only a flow of around 0.2 l/s from this source, which is much less than the village needs.

The prison farm at Sainai obtains water from a spring high on the eastern slope which is piped under gravity.

In 1990 two test wells were drilled at 'Ohonua and Kolomaile. The first was to test the presence of a fresh water lens on the western half of the island. The second to test for perched water on the projected continuation of the volcaniclastic layer west of the cave systems.

The well at 'Ohonua intersected fresh water (1100 uS/cm) close to sea level and was subsequently equipped

DIVISION	ISLAND
'EUA	'EUA
LATITUDE	LONGITUDE
^{0} 'S	^{0} 'W

AREA	COASTLINE	ELEVATION
87.824 km^2	45.228 km	312 m

VILLAGES	POPULATION	HOUSEHOLDS
'Ohonua	1243	214
Tufuvai	163	27
Pangai	252	52
Houma	271	52
Ha'atu'a	471	92
Angaha	370	61
Futu	243	44
'Esia	162	34
Sapa'ata	134	24
Fata'ulua	211	32
Mu'a	151	30
Tongamama'o	198	30
Petani	283	47
Mata'aho	241	48
Total	4393	790

Fig. 6.2.3b

6.2.4 'Atata

Hydrogeology

'Atata is a small island on the north west side of Tongatapu. It was visited in 1991 to assess the water supply and to carry out a geophysical investigation. This is a unique island in Tonga as it contains one village and a tourist resort.

The island is of two parts, similar to Kotu in Ha'apai. At one end is a circular hill, 15 metres above sea level, comprised of uplifted coral limestone with a volcanic ash soil. The rest of the island is a sand spit several hundred metres long and less than one hundred wide. The resort is at the end of the sand spit and the village is at the base of the hill at the other end of the spit.

The resort has a well which was improved into a cross-shaped gallery. The fresh water lens is very thin and excess pumping or drought caused the water to turn salty in 1992.

An EM-34 study was carried out between the village and the top of the hill. The survey indicated that water under the village was salty, however the quality improved towards the centre of the island.

Water Supply

The resort obtains its water from rainwater tanks and the improved well. The village uses rainwater tanks and catchments. During 1991 and 1992 water supplies became very short in the drought and water had to be frequently shipped from Tongatapu.

Improvements

The water supply can be improved with more water tanks and improvements to the guttering. There are two options for a groundwater Supply to the village. The first is a well drilled in the middle of the hill and the second could be an infiltration gallery along the sand spit. The latter may be affected by contamination from the pigs and so the former option is recommended. As the island is not served by cargo vessels the option of using solar powered pumping could be considered.

DIVISION	ISLAND
TONGATAPU	ATATA
LATITUDE	LONGITUDE
$21^0 03'S$	$175^0 15'W$

AREA	COASTLINE	ELEVATION
0.550 km^2	4.061 km	15 m

VILLAGES	POPULATION	HOUSEHOLDS
'Atata	197	29

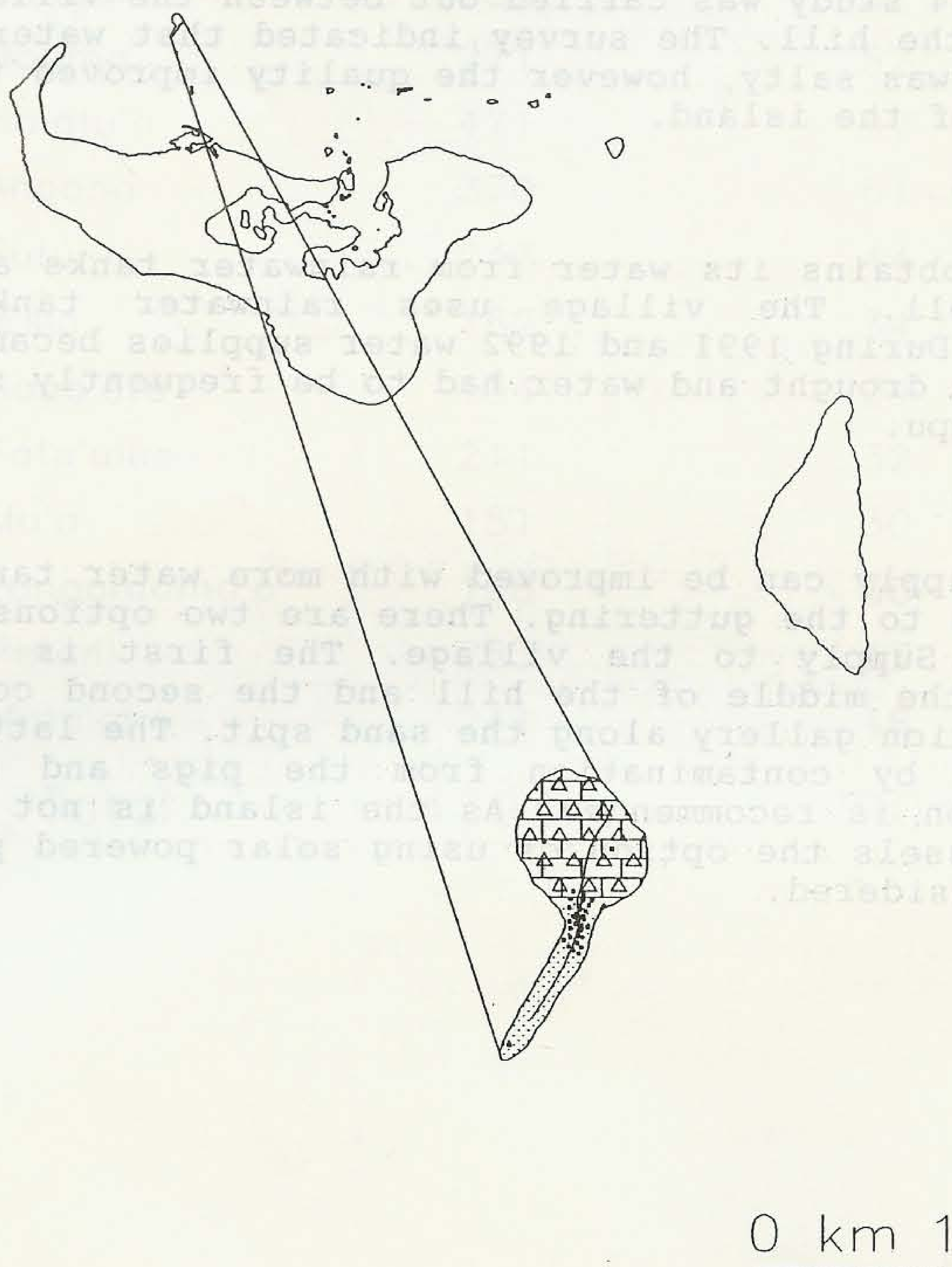


Fig. 6.2.4

6.2.5 'Euaiki

Hydrogeology

This is a small island located to the north east of Tongatapu. It is nearly circular in plan and is made of mostly uplifted coral limestone with a distinctive terrace. Only a small part of the island has sand near the village. The rest has a covering of volcanic ash soil. It has a maximum elevation of 40 metres.

There is only one well on the island in front of the village, which is reported to be fresh.

Water Supply

The village obtains its water supply from rainwater tanks, catchments and a single well. During the drought in 1991 and 1992, the island ran short of water and had to ship water from Tongatapu. The well is reported to be poorly protected from contamination from objects blowing in to the large cavity.

Improvements

The water supply of 'Euaiki can be improved with additional rainwater tanks and Improvements to the guttering. There is little scope for the use of groundwater due to the difficult access to the island for drilling equipment.

DIVISION	ISLAND
TONGATAPU	'EUAIKI
LATITUDE	LONGITUDE
21^0 07'S	174^0 59'W

AREA	COASTLINE	ELEVATION
1.110 km^2	3.952 km	40 m

VILLAGES	POPULATION	HOUSEHOLDS
'Euaiki	85	19

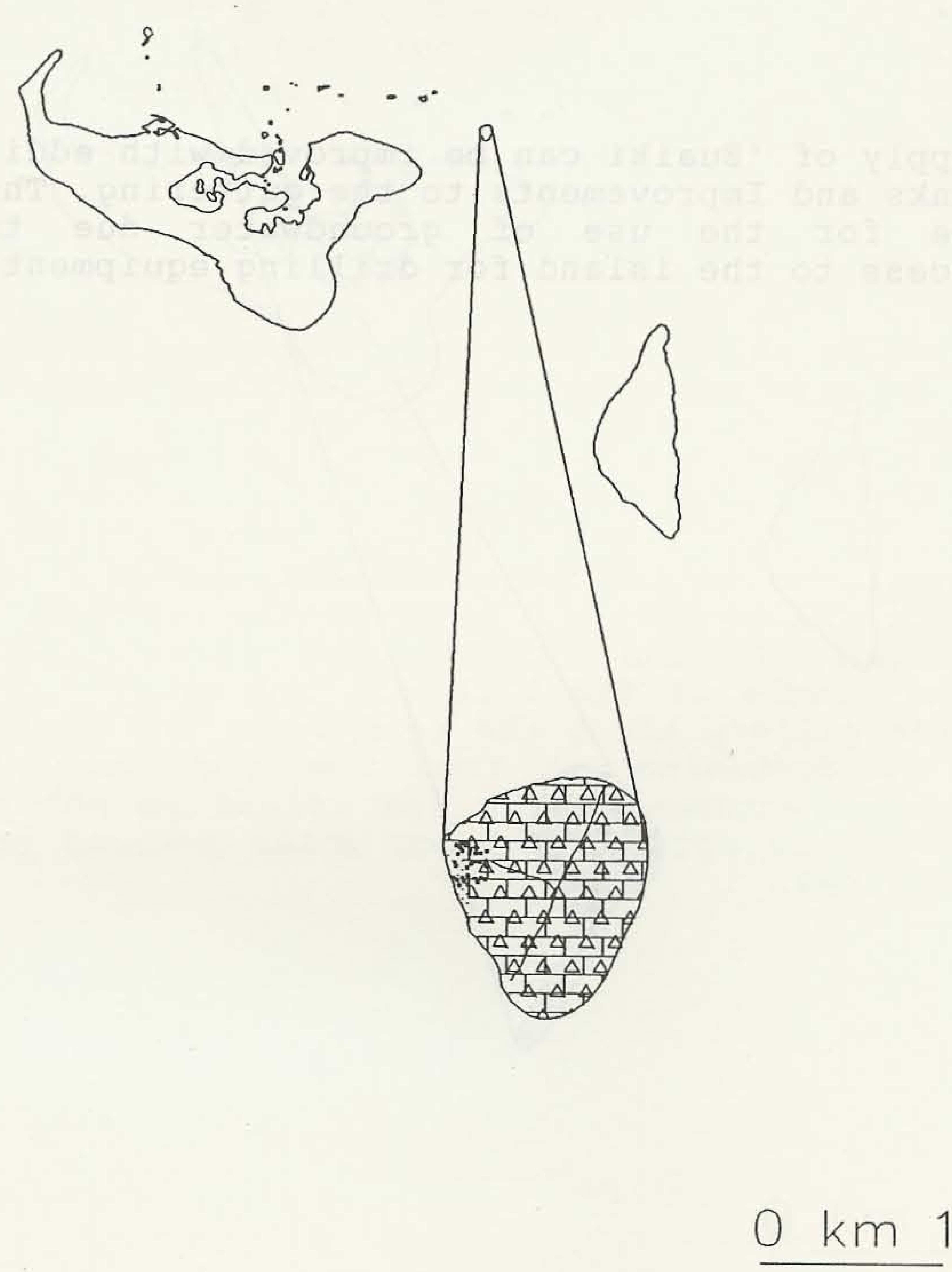


Fig. 6.2.5

6.2.6 Resort Islands

Hydrogeology

The resort islands of Pangaimotu, Fafa and Makaha'a and the neighboring islands which are occasionally visited have limited water supplies. They are nearly flat islands up to five metres above sea level. They are mostly comprised of sand above sea level, with limestone close to sea level or slightly below. Indications on all islands suggest that there is a small fresh water lens. Some have a shallow well near the centre of the island which contains reasonably quality water for sanitation. There is beach rock exposed in places around the shore indicating fresh water.

Water Supply

The resort islands rely mainly on rainwater collected from the facilities and stored in tanks. Limited use of wells is made.

Improvements

Improvements to the water supplies can be made of increased guttering and storage facilities. There is only limited scope for groundwater use. Development of the groundwater would best be affected by installation of infiltration galleries in the centre of the islands.

6.3 Ha‘apai Group

DIVISION 'EUA ISLAND 'EUA

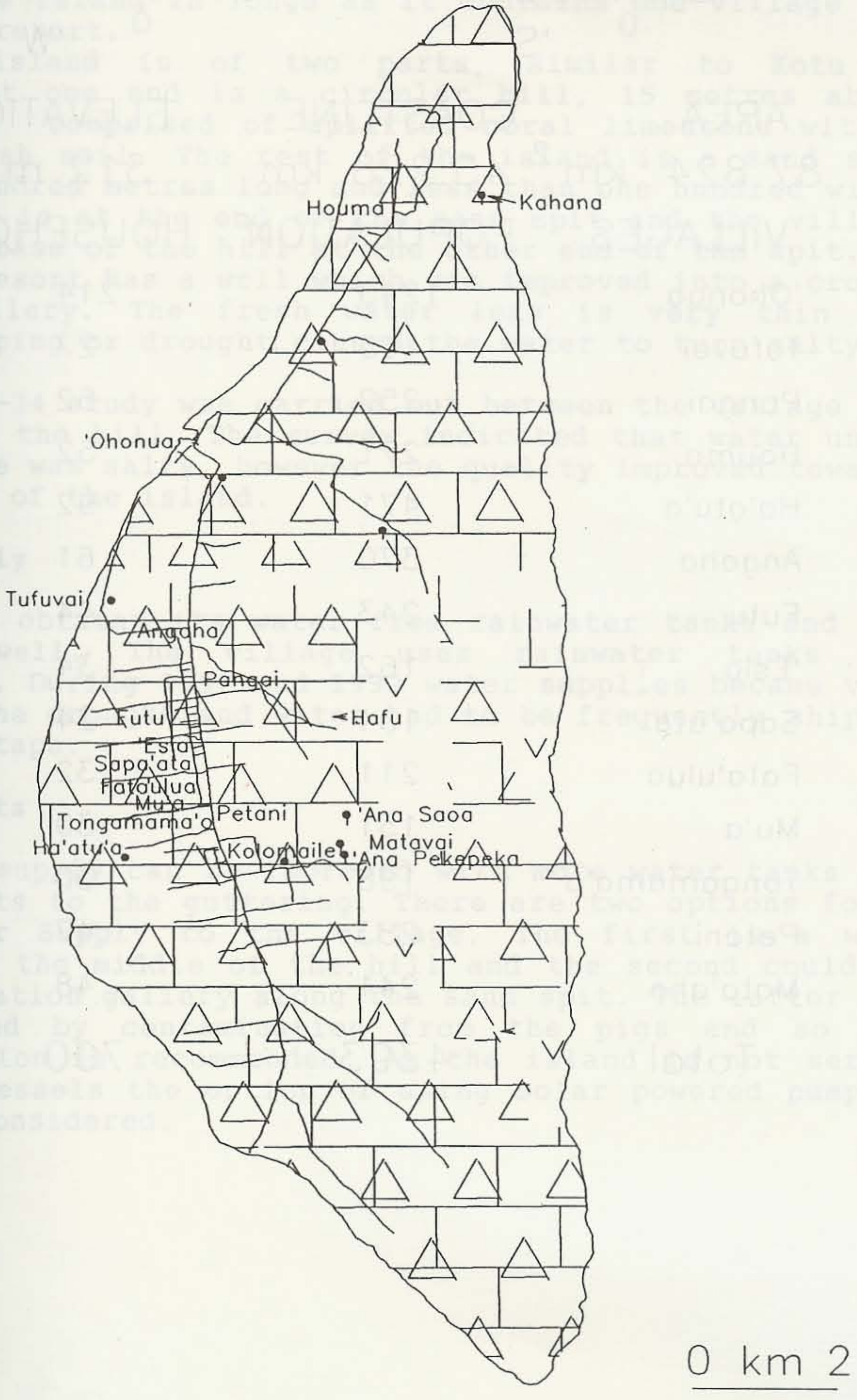


Fig. 6.2.3a

6.3 Ha'apai Group

6.3.1 Description

The Ha'apai Group are located 100 to 120 kilometres to the north of Nuku'alofa. There are a number of small low-lying limestone and sand islands of which 16 are permanently inhabited. The volcanic island, Tofua has a small resident population.

The islands fit into three geological types; low-lying limestone and sand, uplifted limestone and volcaniclastic sediments. The low-lying islands are slightly tilted and tend to have a sand accretion on one side. The uplifted limestone islands are similar to the islands of Vava'u with rugged cliffs and little modern reef development. The volcaniclastic islands in the Nomuka sub-group have possibly been uplifted to such an extent that the underlying volcaniclastic sediments were exposed above sea level before reef development could take place.

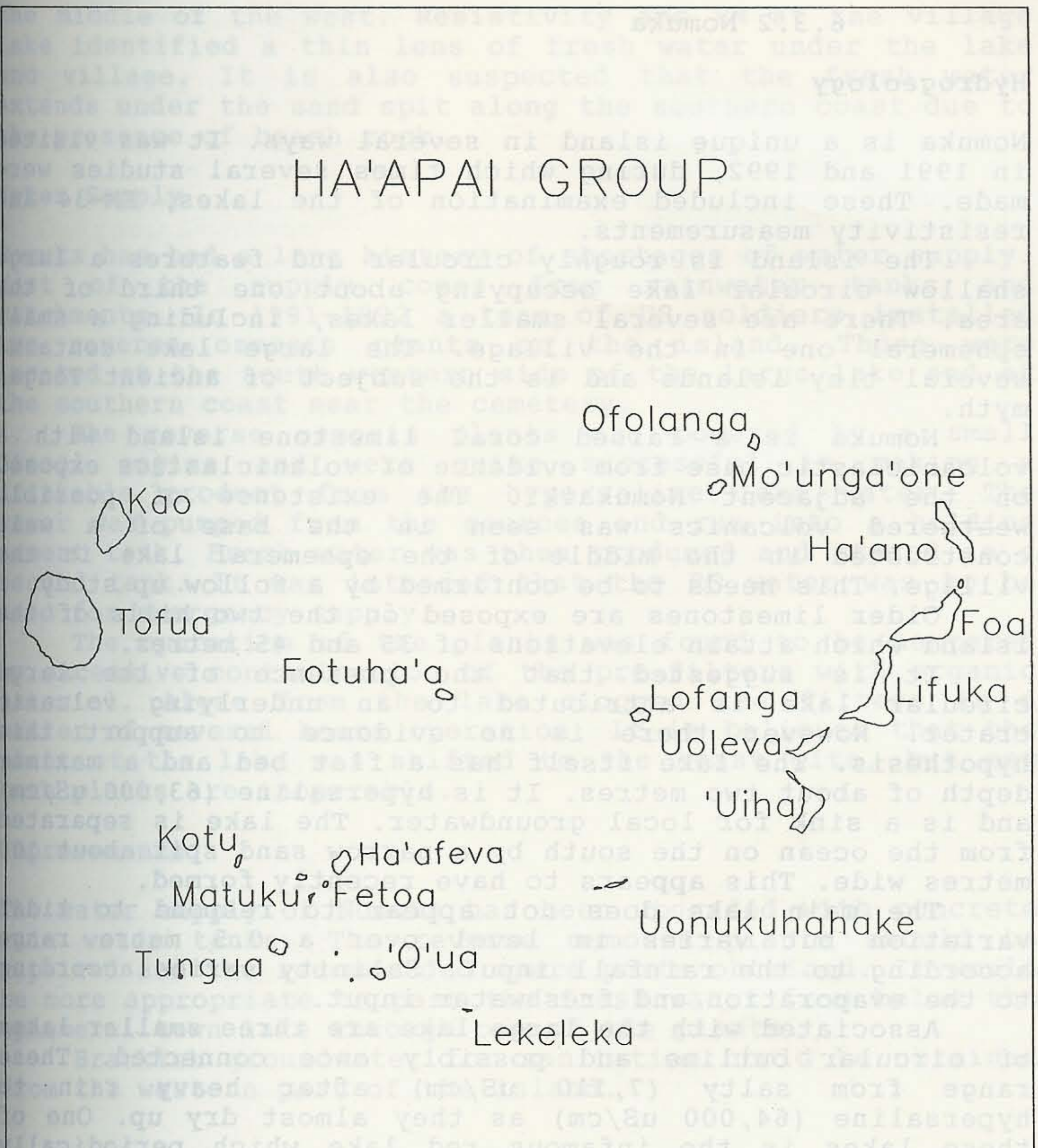
Because of the smallness of the Ha'apai islands and the lower rainfall than the other groups, the occurrence of groundwater is much less assured. Past experience with wells on Lifuka, Foa and 'Uiha has lead to salt water intrusion into the fresh water.

The current studies have identified different characteristics of the two types of aquifers present on some of the islands. The main aquifer is the highly porous limestone. Frequently this high porosity allows the mixing of the underlying sea water during tide cycles with the infiltrating rainwater and thus preventing the development of a fresh water lens.

The second aquifer occurs in the sandy accretions on the lee side of the islands. In places the coral sand is very weakly cemented into a sand rock. This aquifer has a lower porosity and a lower tidal efficiency which allows the formation and preservation of a fresh water lens.

Another factor which locally affects the formation of a fresh water lens is the presence of a volcanic ash (clay) around the present day sea level. The clay layer was identified during well drilling on Lifuka in 1992. This clay acts as a perching layer. It is possible that it occurs on other islands as volcanic ash layers are widely distributed.

On the island of Foa there is a layer which has the opposite effect. There is a large swamp with a semi-permeable base of organic material. This perches rainwater on the top, but prevents the percolation below the swamp to form a fresh groundwater, thus the groundwater is very salty beneath and surrounding the swamp. This effect was also observed in Ha'afeva and in Vava'u on several islands.


HA'APAI GROUP
Ofolanga
Mo'unga'one
Kao
Ha'ano
Tofua
Foa
Fotuha'a
Lofanga
Lifuka
Uoleva
Uiha
Kotu
Ha'afeva
Matuku
Fetoa
Uonukuhahake
Tungua
'O'ua
Lekeleka
Nomuka
Fonoifua
Nomuka Iki
Mango
Telekivavau
Lalona
Fig. 6.3.1

6.3.2 Nomuka

Hydrogeology

Nomuka is a unique island in several ways. It was visited in 1991 and 1992, during which times several studies were made. These included examination of the lakes, EM-34 and resistivity measurements.

The island is roughly circular and features a large shallow circular lake occupying about one third of the area. There are several smaller lakes, including a small ephemeral one in the village. The large lake contains several tiny islands and is the subject of ancient Tongan myth.

Nomuka is a raised coral limestone island with a volcaniclastic base from evidence of volaniclastics exposed on the adjacent Nomukaiki. The existence of possible weathered volcanics was seen in the base of a well constructed in the middle of the ephemeral lake in the village. This needs to be confirmed by a follow up study.

Older limestones are exposed on the two hills of the island which attain elevations of 35 and 45 metres.

It is suggested that the presence of the large circular lake is attributed to an underlying volcanic crater. However there is no evidence to support this hypothesis. The lake itself has a flat bed and a maximum depth of about two metres. It is hypersaline (63,000 uS/cm) and is a sink for local groundwater. The lake is separated from the ocean on the south by a narrow sand spit about 100 metres wide. This appears to have recently formed.

The main lake does not appear to respond to tidal variation but varies in level over a 0.5 metre range according to the rainfall input. Salinity varies according to the evaporation and freshwater input.

Associated with the large lake are three smaller lakes of circular outline and possibly once connected. These range from salty (7,110 uS/cm) after heavy rain to hypersaline (64,000 uS/cm) as they almost dry up. One of these lakes is the infamous red lake which periodically becomes bright pinkish red. The phenomenon was once taken as a sign of imminent volcanic eruption. The real cause is the presence of an algae on the salt surface when the lake is drying out.

The lake in the village is circular and ephemeral. It is perched rain water which reaches a maximum depth of less than one metre. After heavy rain it fills up and contains fresh, albeit heavily polluted water. During most of 1992 it was dry and the water had contracted to about one metre below the lake bed which consists of brown clay. Several wells were dug at this time to water animals. The water was still fresh (1116 uS/cm). There are no other wells on the island.

An EM-34 study was made on the western part of the island. This indicated salt water intruding several hundred metres into the island with possibly brackish water near the middle of the west. Resistivity and EM at the village lake identified a thin lens of fresh water under the lake and village. It is also suspected that the fresh water extends under the sand spit along the southern coast due to the presence of beach rock.

Water Supply

Nomuka has had a long history of shortages of water supply. Most of the supply comes from rainwater tanks and catchments. In 1991-1992 a team of US soldiers installed two reverse osmosis plants on the island. These were located at the south western side of the large lake and at the southern coast near the cemetery.

The reverse osmosis plants are powered by a small diesel engine and were quite successful in making a drinkable product from the hypersaline lake water. The water was pumped from the sources and run into a holding cement tank. Fresh water was then produced and stored in a second tank. It was intended that the RO water was to be used for emergency supply.

The operation of the plants was found to be hampered by excessive contamination of the pre-filters with organic material. Algae from the lake clogged the filters in a matter of several hours operation. It is believed that the plant at the lake was shifted to the coast site, but now both plants are inoperable.

Improvements

The water supply of Nomuka has been upgraded with concrete rain water tanks. The reverse osmosis plants should be repaired and the recommended spare parts obtained. It would be more appropriate to pass the fresh water from below the ephemeral town lake through one of the plants.

Brackish groundwater for sanitation could be obtained from the western part of the island.

DIVISION		ISLAND
HA'APAI		NOMUKA
LATITUDE		LONGITUDE
20^0 15'S		174^0 48'W
AREA	COASTLINE	ELEVATION
6.328 km^2	14.760 km	45 m
VILLAGES	POPULATION	HOUSEHOLDS
Nomuka	686	132

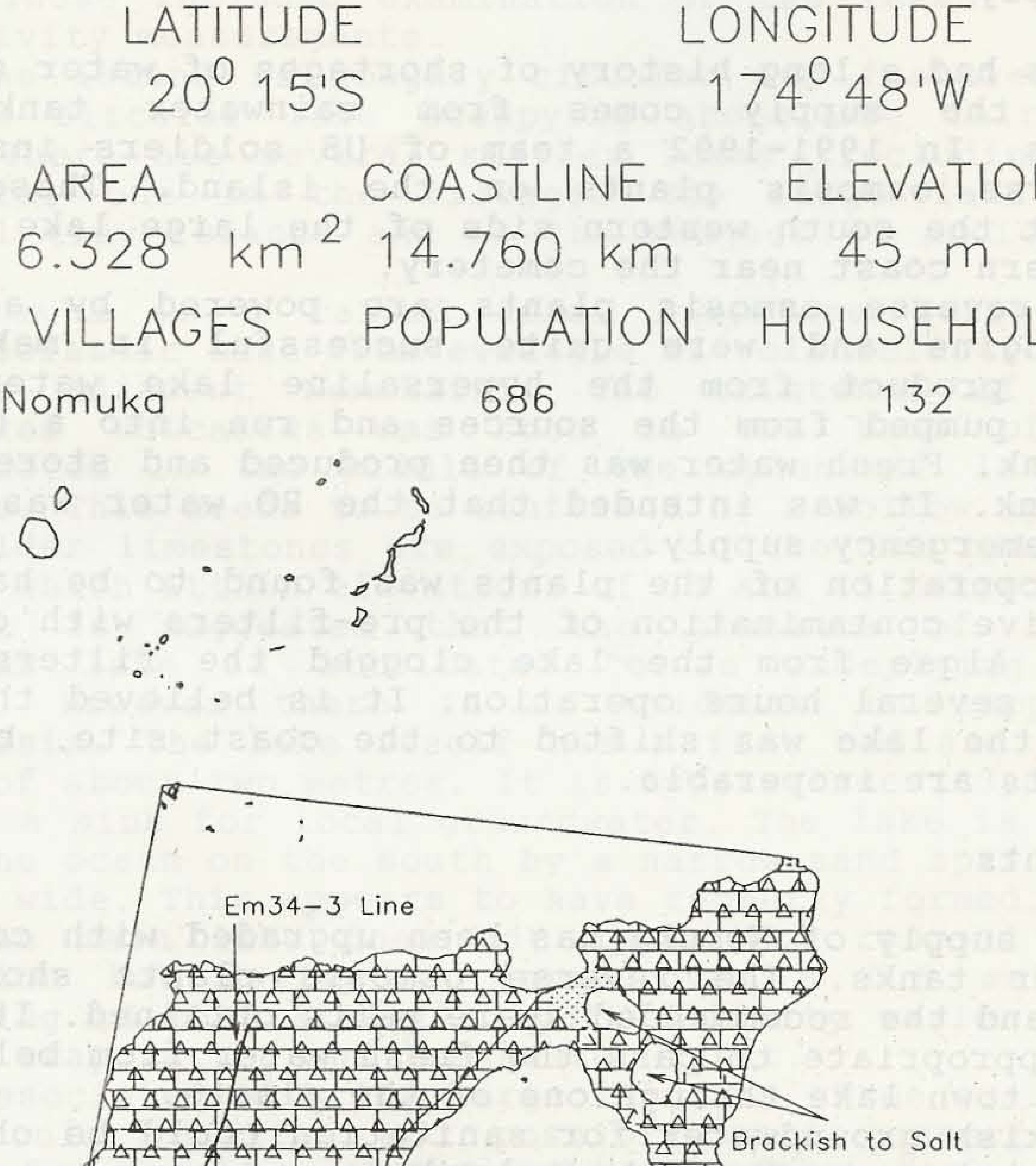


Fig. 6.3.2

6.3.3 Mango

Hydrogeology

The island of Mango was inspected twice in 1992. A census of wells was carried out and geological observations made. The island is small and elongated in an east-west direction. It shows a rugged relief reaching an altitude of 25 metres.

The island is dominated by a volcaniclastic lithology. This includes a finely laminated white tuff formation on the north coast and a greenish grey breccia elsewhere. The volcaniclastics are covered by a younger volcanic ash soil where the slopes are low. On steep slopes the soils are derived from the volcaniclastic parent materials.

Along the western end of the island and underneath the village is a young sand accretion to the island. This is considered to be the only aquifer on the island. The water quality is fresh to salty (1200-7,888 uS/cm). Close to the volcaniclastic hill behind the village the salinity is highest (7,888 uS/cm).

Water Supply

The current water supply comes from cement water tanks and rainwater catchments. There are about five private hand dug wells.

Improvements

A groundwater supply for the island is possible from a well located several hundred metres behind the village under a large mango tree (1200 uS/cm). As this is a remote island it would be worthwhile considering using a solar powered pump.

DIVISION		ISLAND
HA'APAI		MANGO
LATITUDE		LONGITUDE
$20^0 20'S$		$174^0 27'W$
AREA	COASTLINE	ELEVATION
0.771 km^2	4.634 km	25 m
VILLAGES	POPULATION	HOUSEHOLDS
Mango	83	18

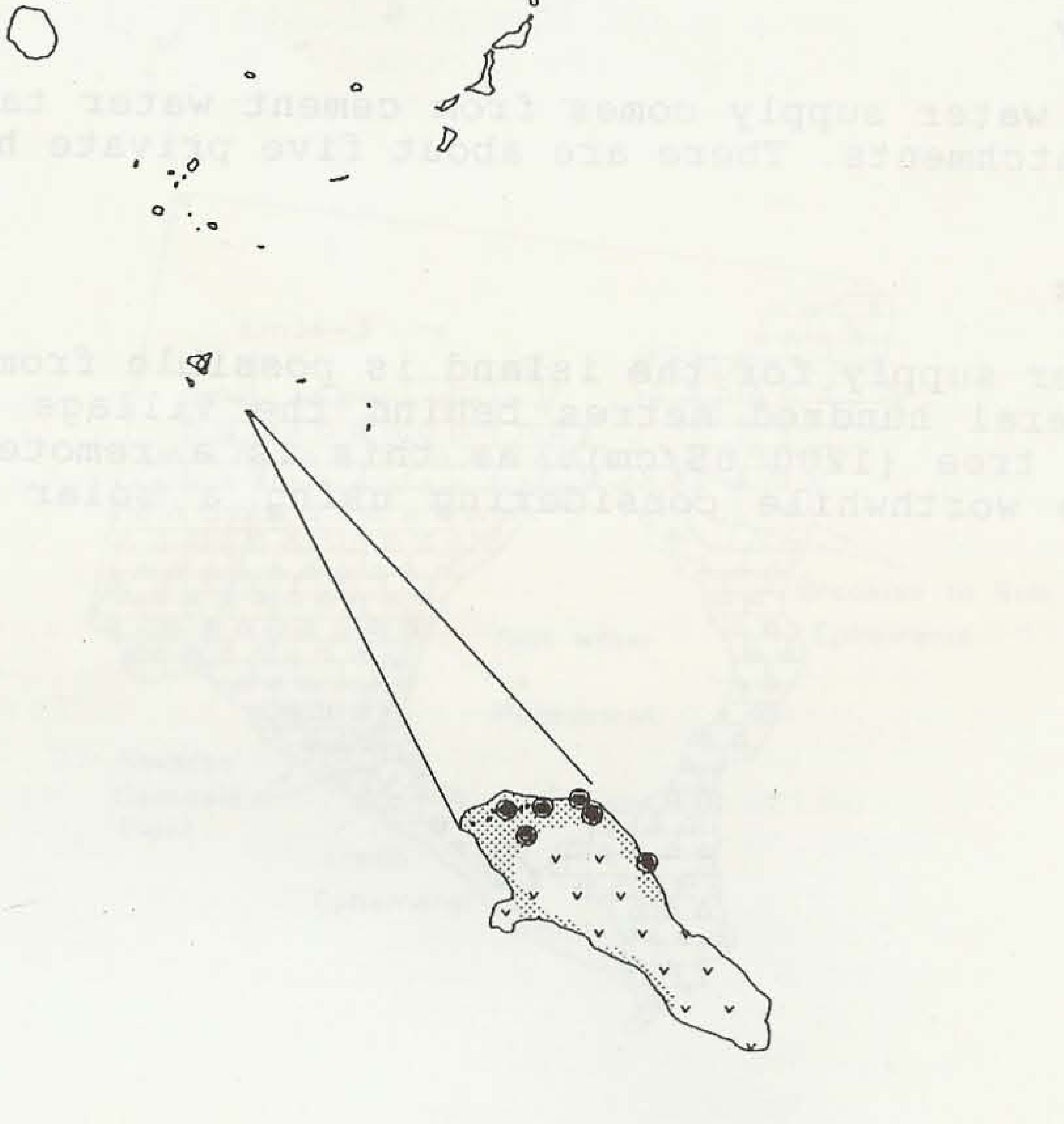


Fig. 6.3.3

6.3.4 Fonoifua

Hydrogeology

Fonoifua was visited in 1992 and a well census was taken together with a geological inspection. This is a very small island which is dominated by a steep hill along the centre rising to about 25 metres. Most of the island is constructed of volcaniclastic tuff in fine, slightly dipping beds. On the top of the hill on lesser slopes there is a volcanic ash soil. Elsewhere on steeper slopes the soils are a thin derivative of the parent volcaniclastic material.

Along the south western side of the island is a small sandy accretion on which the village was established. This forms a small aquifer. The water may be fresh in part, but was salty (15,000 uS/cm) in a small well near the western end of the village.

Water Supply

The island is supplied with rainwater from tanks, and catchments. One catchment is located on the hill above the village. Water was once piped down the hill to a tap. The system is in a state of disrepair.

Improvements

The major improvements could include additional cement tanks. There is little prospect for fresh groundwater, but on the western end of the island brackish groundwater could be obtained for sanitation.

DIVISION		ISLAND
HA'APAI		FONOIFUA
LATITUDE		LONGITUDE
20^{0} 17'S		174^{0} 38'W
AREA	COASTLINE	ELEVATION
0.446 km^{2}	3.291 km	25 m
VILLAGES	POPULATION	HOUSEHOLDS
Fonoifua	111	22

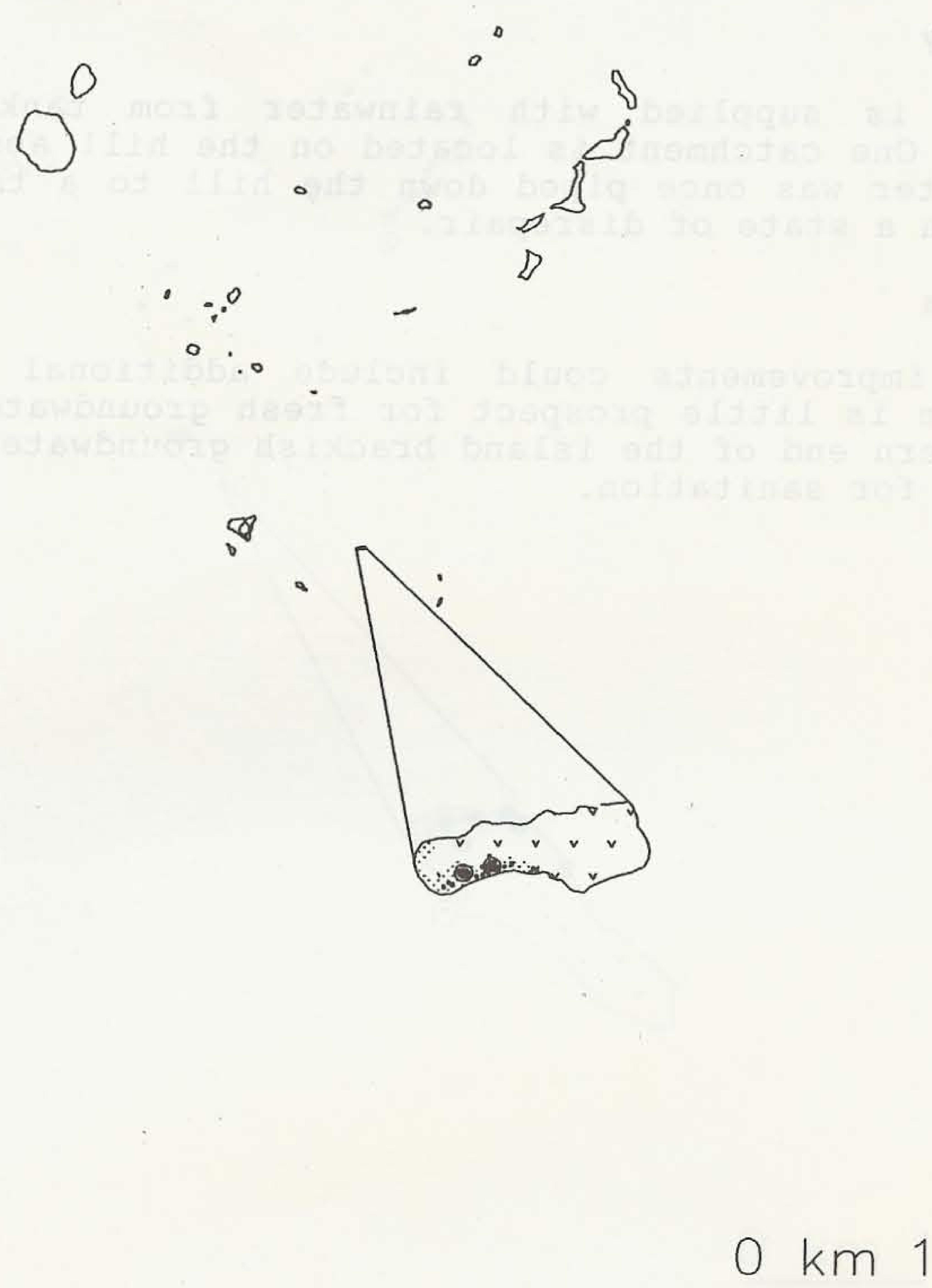


Fig. 6.3.4

6.3.5 'O'ua

Hydrogeology

'O'ua was visited in 1992 to inspect the water supply facilities and to conduct EM-34 studies. The island is roughly circular and is elevated coral limestone reaching a maximum elevation of 25 metres above sea level. It has a volcanic ash soil over most of the area and there are steep slopes around its perimeter.

There are no wells on the island, but the EM-34 study indicated that fresh to brackish water exists under the island.

Water Supply

Existing water supplies come from rain water tanks and catchments.

Improvements

Improvements to roof guttering will improve the yield of rain water. Additional cement tanks are needed.

Groundwater development is possible as this island is considered large enough to have fresh groundwater. Access for drilling equipment is difficult. It would require a landing barge to approach the southern landing with a bull dozer. The dozer could improve the steep track and transport the drilling equipment to the middle of the island behind the village. Probably two wells would be necessary.

DIVISION		ISLAND
HA'APAI		'O'UA
LATITUDE		LONGITUDE
20° 03'S		174° 41'W
AREA	COASTLINE	ELEVATION
0.942 km^2	3.886 km	25 m
VILLAGES	POPULATION	HOUSEHOLDS
O'ua	266	47

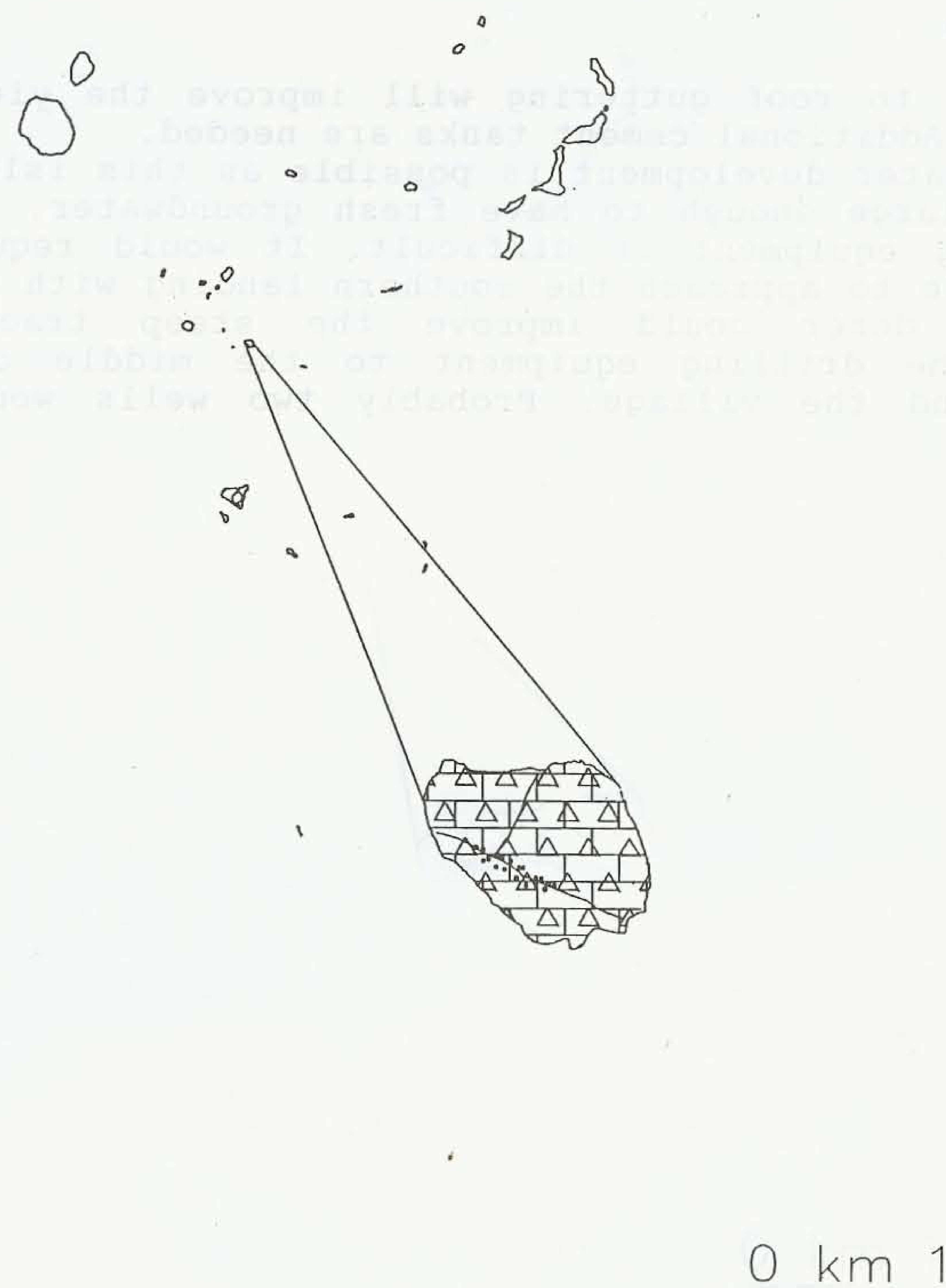


Fig. 6.3.5

6.3.6 Ha'afeva

Hydrogeology

In 1992 an inspection of the island included a census of wells and observations of the hydrological features.

The island is roughly rectangular and flat reaching a maximum elevation of about 10 metres. It is a coral limestone island with a covering of volcanic ash on the more elevated parts and sand on the lower fringes. The elongated village is mainly on the sand.

The island has some unique features of internal swamps, possibly former lagoons. There is one at the back of the village, two in the centre of the island and a small one towards the south. The swamps indicated that water in the sandy areas around the village was fresh (292 uS/cm), but near the centre of the island the groundwater windowed in the swamps is salty (2,190, 3,240 uS/cm). The middle swamps contain some perched rainwater.

There are numerous hand dug private wells in the village with fresh water (916-1600 uS/cm), some quite close to the sea.

Water Supplies

These are obtained from rain water tanks and catchments. Extensive use is made of the private wells. Many were equipped with PVC pipe hand pumps.

Improvements

Improvements to roof guttering and the number of tanks is required. It is feasible to consider groundwater development on the island due to the extensive areas of sand around the perimeter. This would require additional investigation with the EM-34 equipment to site the location of wells. Probably at least five wells would be necessary, widely spaced and pumping no more than 0.5 l/s.

The island is regularly served by passenger and cargo ferries, but unloading fuel supplies is difficult. Therefore the use of solar powered pumping could be considered.

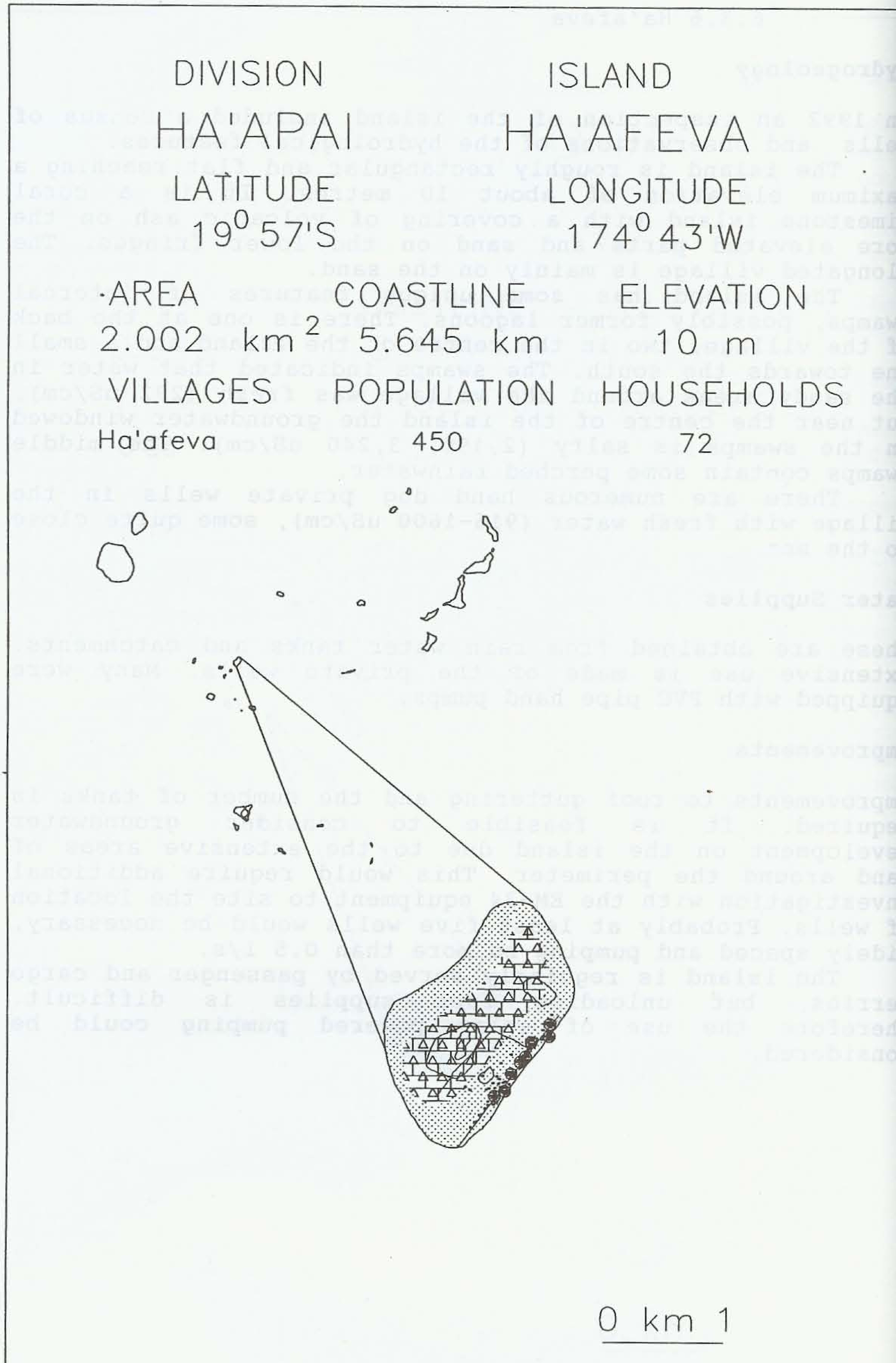

DIVISION
ISLAND
HA'APAI
HA'AFEVA
LATITUDE
LONGITUDE
19° 57'S
174° 43'W
AREA
COASTLINE
ELEVATION
2.002 km²
5.645 km
10 m
VILLAGES
POPULATION
HOUSEHOLDS
Ha'afeva
450
72
0 km 1

Fig. 6.3.6

6.3.7 Tungua

Hydrogeology

Tungua was visited in 1992 when a well census and inspection was made. This is a flat island reaching about 15 metres above sea level. It is roughly square and comprises mostly coral limestone covered with a volcanic ash soil. Around part of the perimeter on the east and north there is a sandy accretion. The village covers a large part of the sand on the east.

Around the coast there is strong evidence of erosion of the weather (south-east) side and redeposition on the lee side. Essentially the island is moving north-west.

There are numerous private wells which are hand dug. The water contained is mostly fresh (1070-1140 uS/cm). The only exception was a well on the south eastern end of the village which was salty (6,888 uS/cm).

The boundary between the sandy and volcanic ash soils is easily seen at the back of the village.

Water Supplies

Water supplies are obtained from rain water tanks and catchments, together with the private wells.

Improvements

Improvements to roof guttering and increasing the number of tanks is required. There is scope for obtaining groundwater supplies, especially on the northern end of the island. Development would require at least three wells equipped with pumps of about 0.5 l/s capacity. Because of the remoteness of the island, the use of solar pumping could be considered.

Further investigation of the groundwater using the EM-34 is necessary to locate suitable sites for the wells.

DIVISION		ISLAND
HA'APAI		TUNGUA
LATITUDE		LONGITUDE
20^{0} 01'S		174^{0} 46'W
AREA	COASTLINE	ELEVATION
1.544 km^{2}	4.611 km	15 m
VILLAGES	POPULATION	HOUSEHOLDS
Tungua	301	52

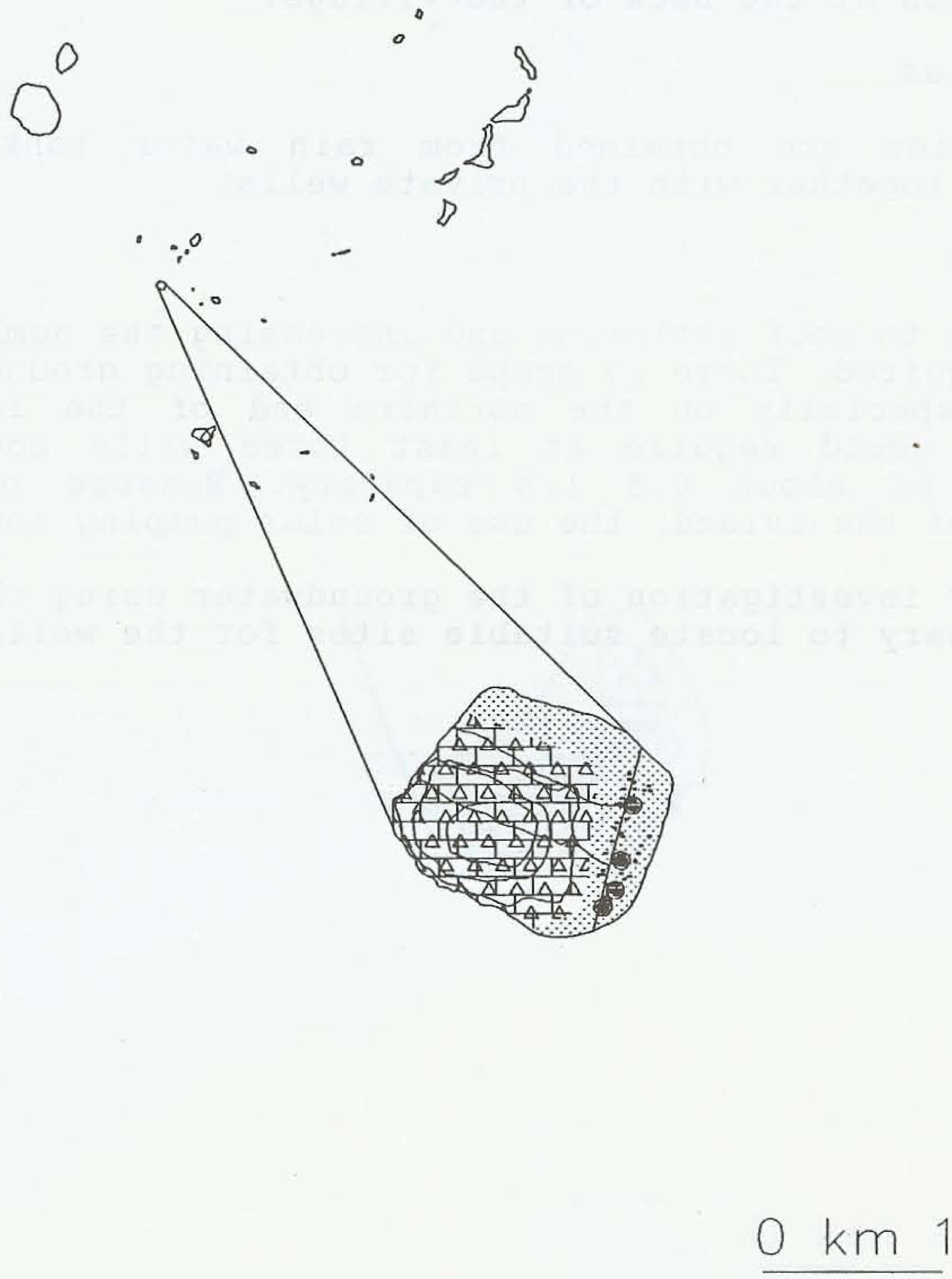


Fig. 6.3.7

6.3.7 Matuku

Hydrogeology

Matuku was visited in 1992 when a well census and inspection was made. It is a very small island, roughly square. It is mostly coral limestone with a volcanic ash soil reaching a maximum elevation of 10 metres. There is a sandy berm on the northern side of the island about 50 metres wide and containing the houses.

Two private wells are located at the back of the village. One was quite fresh (1400 uS/cm), the other salty (8,570 uS/cm).

Water Supply

Apart from the two private wells, water supply is from rainwater tanks and catchments.

Improvements

There is little scope for development of groundwater due to the size of the island and the evidence of a limited fresh water lens. Brackish groundwater could be used for sanitation and improvements made to the roof guttering.

DIVISION		ISLAND
HA'APAI		MATUKU
LATITUDE		LONGITUDE
19^0 58'S		174^0 45'W
AREA	COASTLINE	ELEVATION
0.321 km^2	2.322 km	10 m
VILLAGES	POPULATION	HOUSEHOLDS
Matuku	142	22

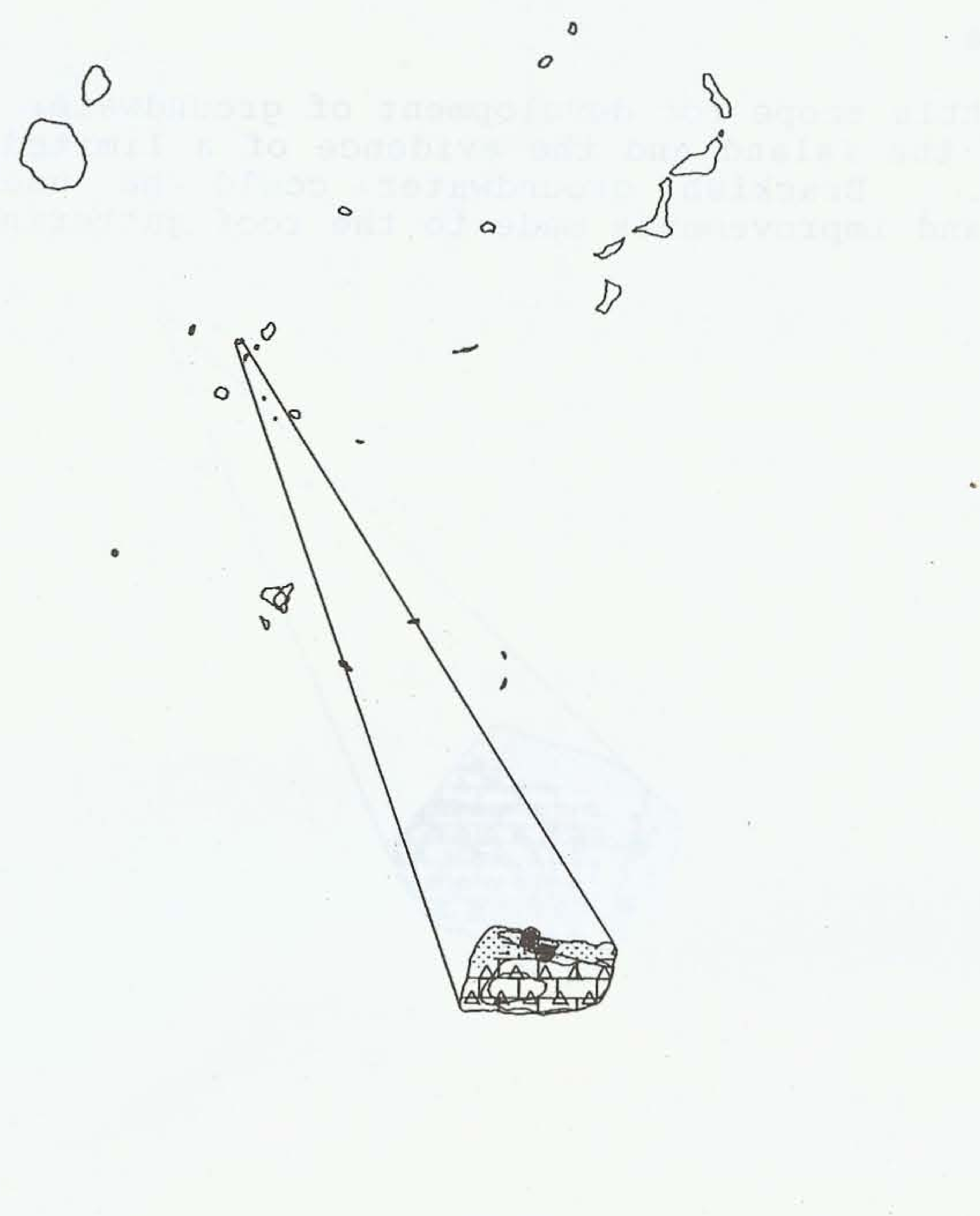


Fig. 6.3.8

6.3.9 Kotu

Hydrogeology

Kotu was visited in 1992 when a census of wells and inspection was made. The island is very small and consists of two distinct features. The southern part of the island is a circular hill up to thirteen metres high. It comprises of coral limestone to about two metres above sea level covered in a very thick, red layer of coarse volcanic ash.

The northern part of the island is little more than a sandy spit a few hundred metres wide and about four metres above sea level. It is on the sandy spit where the charming village is located.

On the western side of the spit is a coastal swamp with a few pools used for bathing. These were tested and found to be salty (30,000 uS/cm).

In the village there are about seven private hand dug wells. Several of these are equipped with PVC hand pumps. The inspection of the wells was made at the end of a long period of drought and most of the wells were salty (1,005-17,390 uS/cm). It is unlikely that the quality will improve greatly during a normal wet season.

Water Supply

Water supply is from rain water tanks and catchments. A limited use is made of the private wells.

Improvements

There is practically no scope for further development of groundwater, due to size of the island and the evidence of salty groundwater. Improvements can be made to the roof guttering and the number of water tanks.

DIVISION		ISLAND
HA'APAI		KOTU
LATITUDE		LONGITUDE
19^{0} 57'S		174^{0} 48'W
AREA	COASTLINE	ELEVATION
0.403 km ^{2}	2.819 km	13 m
VILLAGES	POPULATION	HOUSEHOLDS
Kotu	233	49

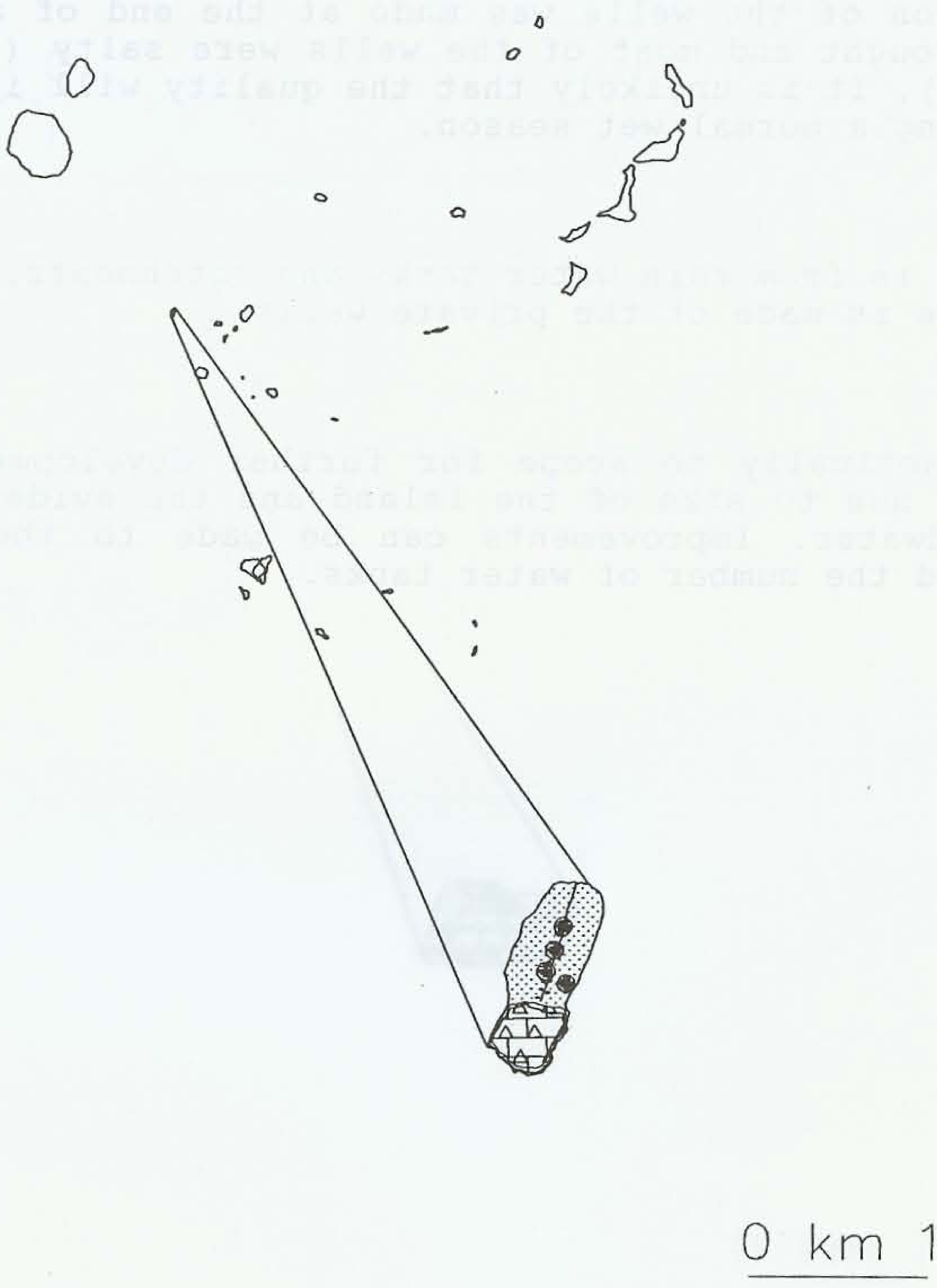


Fig. 6.3.9

6.3.10 Tofua

Hydrogeology

Tofua is a volcanic crater to the west of Lifuka and is roughly circular in outline. It has relatively steep sides all around with little reef development. It contains a large crater lake and the slopes rise to a maximum of 507 metres above sea level.

Within the northern end of the crater is an active cone which continuously emits steam. It has ejected ash and lapili in recent times. There are also several dormant cones around the northern end of the lake.

The lake is reported to have a level about 21 metres above sea level. The water is salty with a conductivity of 22,400 uS/cm. There are no other sources of surface water on the island.

Water Supply

There are two collections of houses which are inhabited during times of cultivation on the island. It is presumed that rain water is the only source of water supply.

Improvements

There is little scope for improving water supply on Tofua. Access to the island is very difficult and it is not practical to contemplate mobilising the drilling rig to the island. Groundwater is likely to exist on the island but in small quantities in the volcanic rock. Provision of small water tanks is a possibility.

DIVISION		ISLAND
HA'APAI		TOFUA
LATITUDE		LONGITUDE
19^{0} 45'S		175^{0} 04'W
AREA	COASTLINE	ELEVATION
45.809 km^{2}	27.777 km	507 m
VILLAGES	POPULATION	HOUSEHOLDS
Hokula, Manaka	89	22

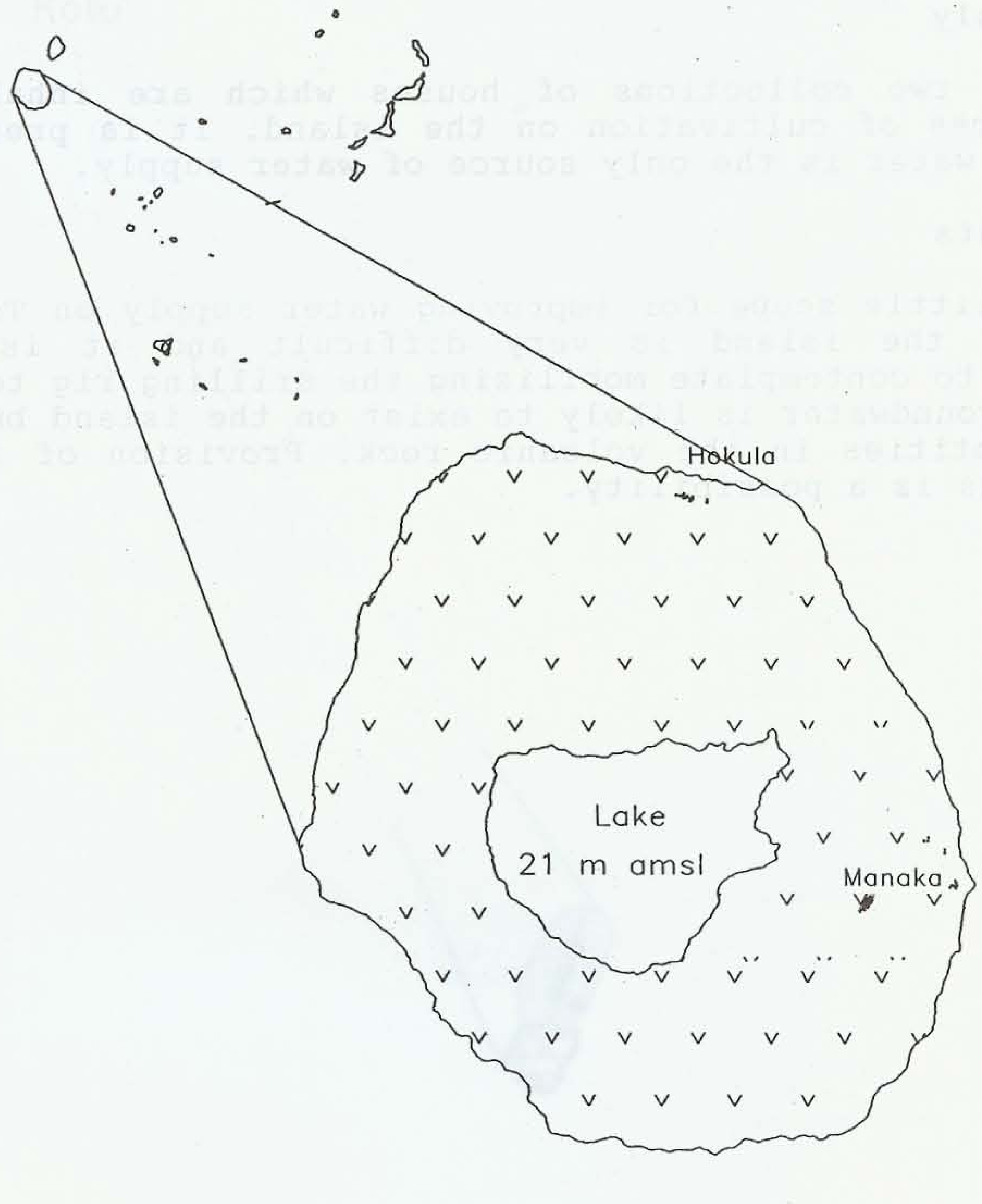


Fig. 6.3.10

6.3.11 Fotuha'a

Hydrogeology

Fotuha'a was briefly inspected in 1992. It is a raised coral limestone island with a thick mantle of coarse volcanic ash and lapili. It is roughly circular reaching a maximum elevation of 40 metres. The island's appearance is similar to the islands in Vava'u. There are steep cliffs around the island with almost no reef development or beaches. Access to the island is very difficult requiring a well timed jump onto the rocks on the western side or, in very calm weather, entrance to a small cove on the south.

Water Supply

There are no wells on the island. Water supplies are entirely from rainwater in tanks and catchments.

Improvements

Improvement to the roof guttering is required. There is no prospect for developing groundwater on the island in the foreseeable future as access to drilling equipment is practically impossible.

DIVISION	ISLAND
HA'APAI	FOTUHA'A
LATITUDE	LONGITUDE
19^0 49'S	174^0 43'W

AREA	COASTLINE	ELEVATION
1.069 km^2	4.288 km	40 m

VILLAGES	POPULATION	HOUSEHOLDS
Fotuha'a	192	33

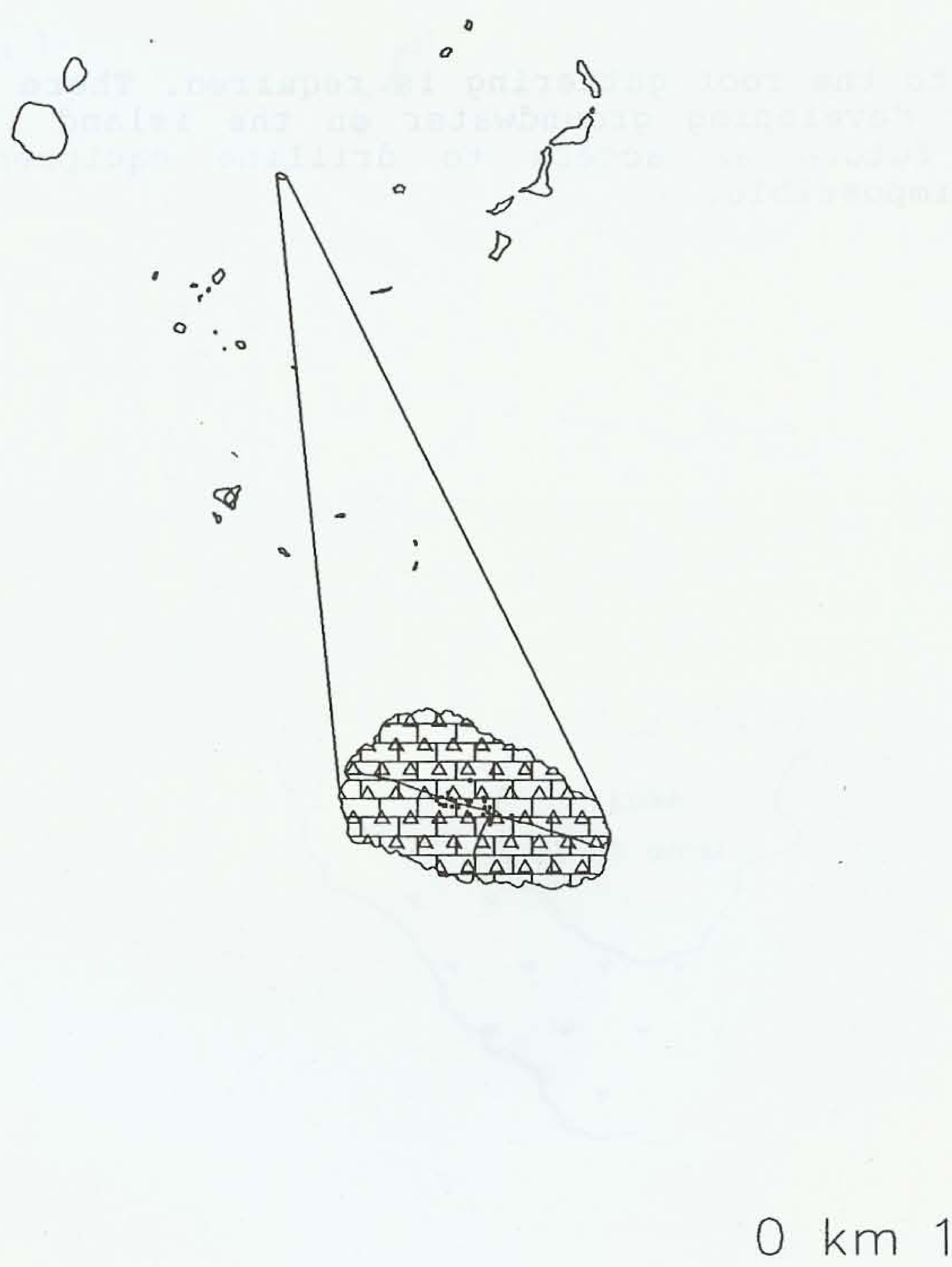


Fig. 6.3.11

6.3.12 Lofanga

Hydrogeology

Lofanga was visited in 1992 and an inspection of the water tanks and geology was made. The island is a raised coral structure reaching a maximum elevation of about 15 metres near the centre of the island. The coral limestone has a blanket of volcanic ash soil. The coastline has a few sandy bays, but these are not considered to be suitable sources of groundwater.

Water Supply

The present water supply is entirely by rainwater tanks and catchments. There are no wells on the island.

Improvements

The water supply can be upgraded by improvements to the roof guttering. Provided that the drilling rig can be landed on the island, it is likely that a well can be developed in the middle of the island. There are suitable drilling sites near the GPS. The island is considered large enough to have a fresh water lens. The well should be equipped with a pump of capacity not greater than 1 l/s.

The relative remoteness of the island would make a solar powered pump worth considering.

DIVISION	ISLAND
HA'APAI	LOFANGA
LATITUDE	LONGITUDE
$19^0 50'S$	$174^0 33'W$

AREA	COASTLINE	ELEVATION
1.508 km^2	5.295 km	15 m
VILLAGES	POPULATON	HOUSEHOLDS
Lofanga	330	50

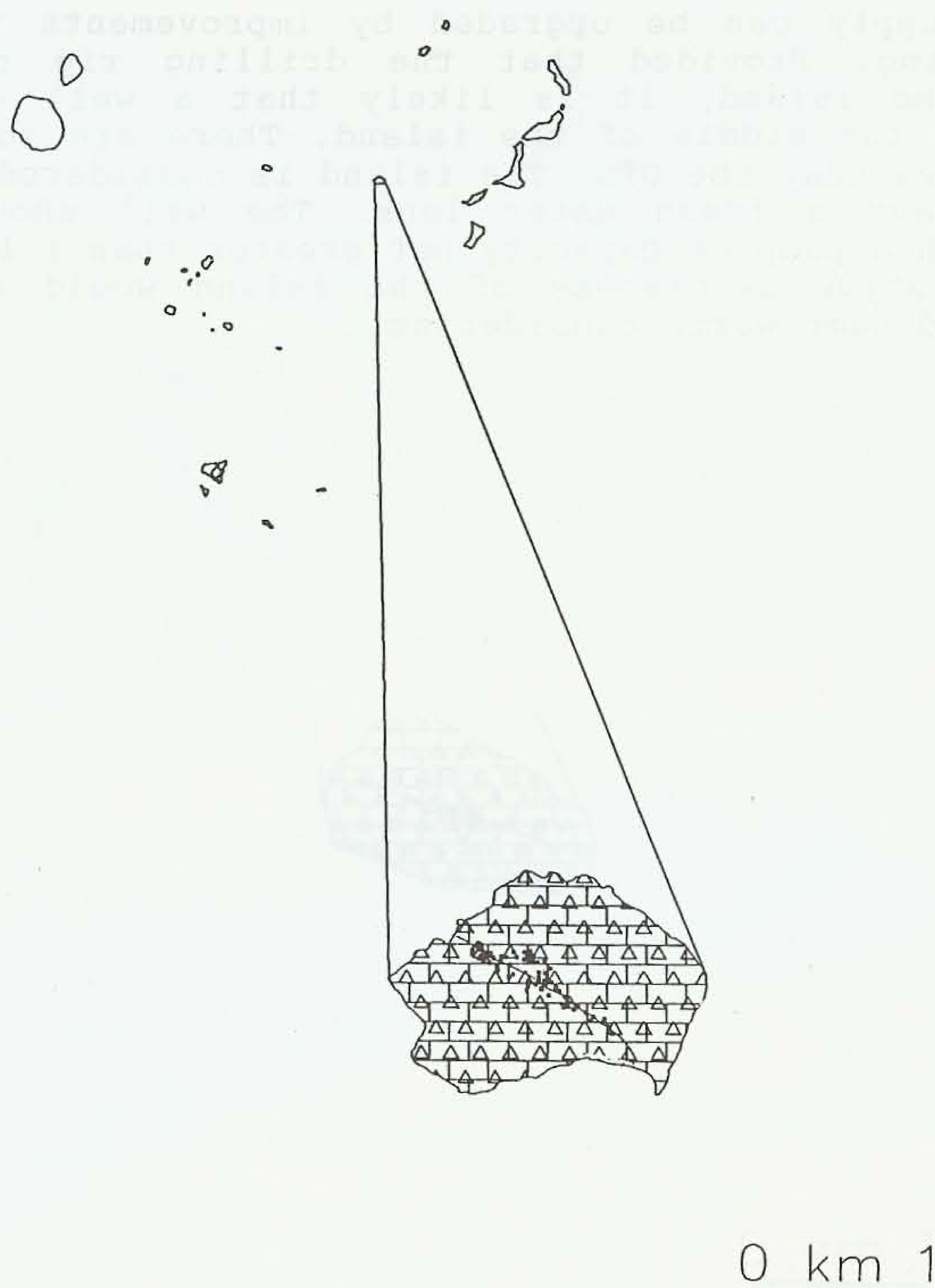


Fig. 6.3.12

6.3.13 'Uiha

Hydrogeology

The island of 'Uiha is roughly rectangular in shape and is tilted from east to west (Fig. 6.3.13a). It is almost flat with the highest part on the eastern coast reaching about 10 metres above sea level. There is a transition in the surface geology about half way across the island. On the low western side there is a sandy soil overlying weakly cemented sand. To the east coral limestone crops out along the coast. It is covered with volcanic ash.

Most of the agricultural production is on the far eastern side of the island in the better soils. Near the centre of the island is a gradational mix of the two main soil types.

Investigations were carried out on 'Uiha in 1990 and 1991. These included monitoring of the two water supply wells, private wells, the traditional well near Felemea and the use of geophysics. The EM-34 indicated that the better quality water lies under the western part of the island, mostly beneath the two villages (Fig. 6.3.13b).

Water Supply

'Uiha has been supplied with fresh water from ancient times by the traditional well to the south of Felemea. It is the subject of an ancient Tongan legend. It was inspected in 1991 and found to be improved with a cement surround and roof. Water quality was very good.

Evidence that there were numerous hand dug wells was found from observations on the western side of the island. In particular there are deep excavations at the south-east corner of 'Uiha village and along the road from 'Uiha to Felemea. There are about four private wells in 'Uiha and one in Felemea. One was located in the bush behind Felemea.

In the 1970's the two villages were each equipped with a hand dug well. These were fitted with Southern Cross Pumps. It was found that the water turned salty after a short period of operation. Pumping had ceased in 1991. The wells returned to being almost fresh after a period of several months ('Uiha 2830 uS/cm, Felemea 2190 uS/cm).

Improvements

Immediate improvements could be effected by the replacement of the existing pumps with pumps of a capacity of 0.5 to 1.0 l/s. Sites for new wells have been selected from the geophysical survey. It is recommended that three new wells be constructed at the eastern side of 'Uiha village and that one be constructed on the south east side of Felemea. These wells and the traditional well at Felemea should be equipped with the same low capacity pumps recommended above.

DIVISION		ISLAND
HA'APAI		'UIHA
LATITUDE		LONGITUDE
$19^{0}54'S$		$174^{0}24'W$
AREA	COASTLINE	ELEVATION
5.457 km^2	11.983 km	10 m
VILLAGES	POPULATION	HOUSEHOLDS
'Uiha	632	113
Felemea	248	58
Total	880	71

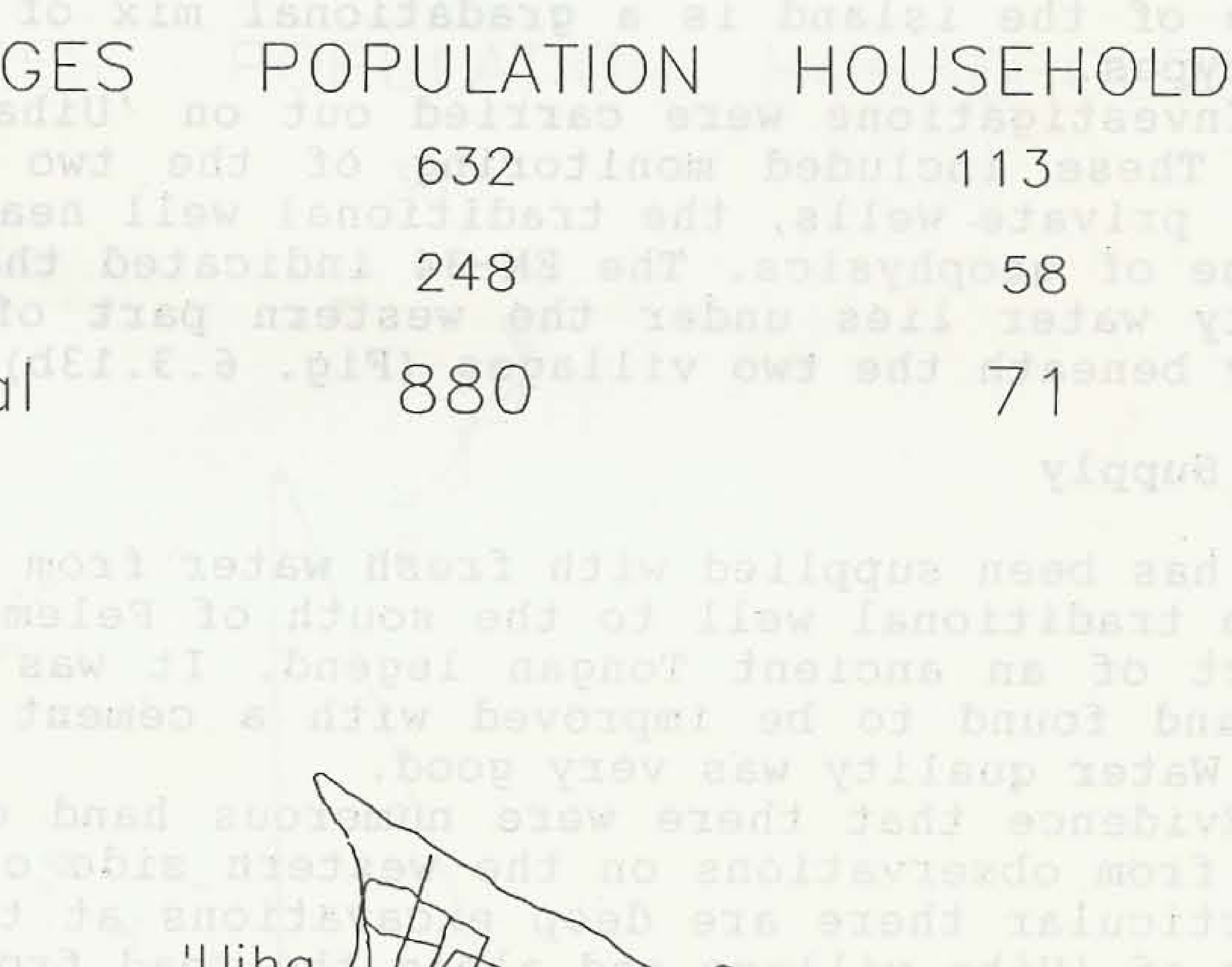


Fig. 6.3.13b

DIVISION	ISLAND	
HA'APAI	'UHA	
LATITUDE	LONGITUDE	
19°54'S	174°24'W	
AREA	COASTLINE	ELEVATION
5.457 km^2	11.983 km	10 m
VILLAGES	POPULATION	HOUSEHOLDS
Uiha	632	113
Felemea	248	58
Total	880	71

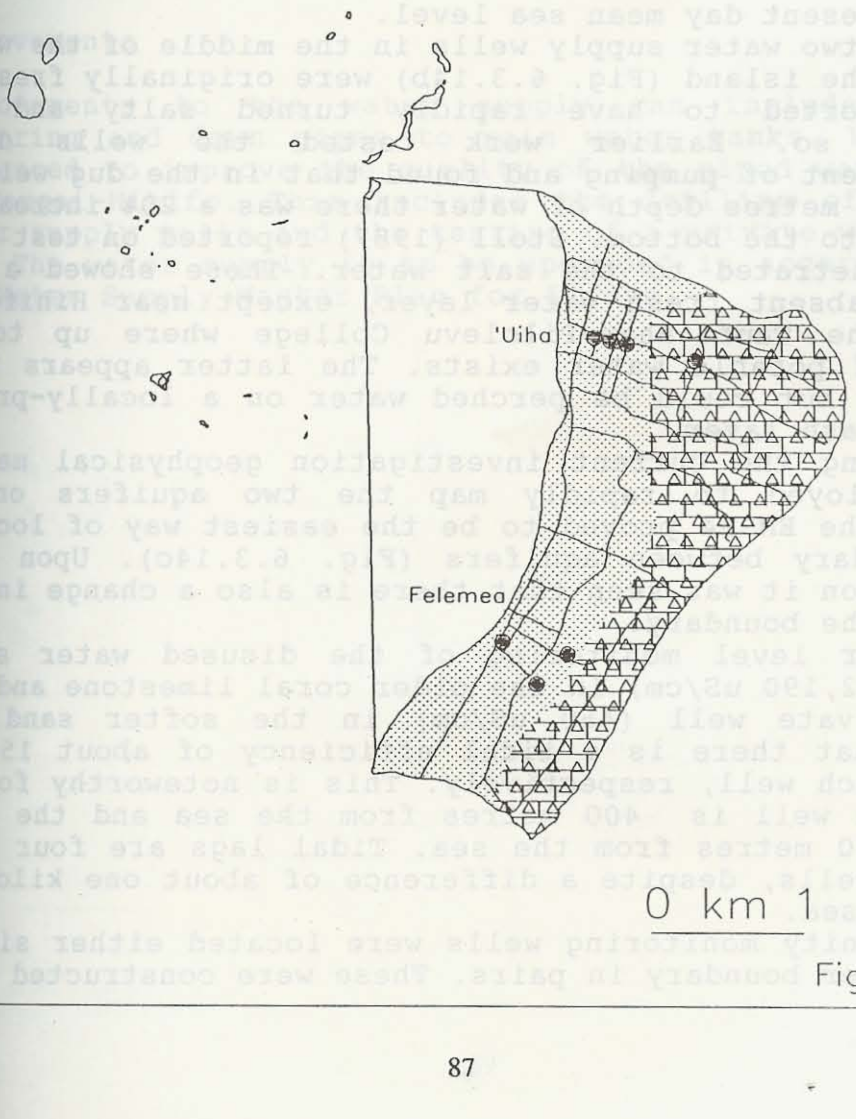


Fig. 6.3.13a

6.3.14 Lifuka

Hydrogeology

The island of Lifuka has been the subject of intensive hydrogeological investigation as it contains the administrative centre and the largest island population of the Ha'apai Group. Investigations have included well census and monitoring, test pumping, drilling, geophysics and geological studies. The impetus to these studies has been a high risk of health problems from private wells, the salty piped-water and political.

The island is the second largest coral island in the Ha'apai Group. It is elongated in a north south direction in a crude approximation of the outline of England. It is low-lying but is slightly tilted from east to west (Fig. 6.3.14a). Maximum elevation of 15 metres is close to the cliff-lined east coast.

The eastern and central parts of the island are coral limestone overlain by up to three metres of volcanic ash soil. On the western side, mainly under the villages is a much younger sandy soil and soft sand rock built up from the accretion on the lee side of the island. Within the soft rock is a discontinuous layer of volcanic ash, close to the present day mean sea level.

The two water supply wells in the middle of the widest part of the island (Fig. 6.3.14b) were originally fresh but were reported to have rapidly turned salty and have remained so. Earlier work tested the wells during commencement of pumping and found that in the dug wells of about 0.5 metres depth of water there was a 20% increase in salinity to the bottom. Stoll (1987) reported on test wells which penetrated to the salt water. These showed a very thin or absent fresh water layer, except near Hihifo and behind the Taufa'ahau-Pilolevu College where up to 6.0 metres of potable water exists. The latter appears to be anomalous but could be perched water on a locally-present volcanic ash layer.

During the current investigation geophysical methods were employed to rapidly map the two aquifers on the island. The EM-34 proved to be the easiest way of locating the boundary between aquifers (Fig. 6.3.14c). Upon later examination it was seen that there is also a change in soil type at the boundary.

Water level monitoring of the disused water supply well 45 (2,190 uS/cm) in the older coral limestone and also in a private well (450 uS/cm) in the softer sand rock showed that there is a tidal efficiency of about 15% and 10% in each well, respectively. This is noteworthy for the sand rock well is 400 metres from the sea and the coral well 1,400 metres from the sea. Tidal lags are four hours in both wells, despite a difference of about one kilometre from the sea.

Salinity monitoring wells were located either side of the aquifer boundary in pairs. These were constructed using

PVC pipes which were slotted at different depths below the water table. In general, they confirmed the readings of the EM-34 and showed that the fresh water layer is very thin or absent on the east and between 0.5 and 6.0 metres thick on the west.

Water conductivity was monitored in the private wells of all the villages of Lifuka. The monitoring showed that most areas are fresh, except for a few wells in Holopeka and Pangai. Some of the wells show signs of being contaminated with salty water from the public water supply.

Water Supply

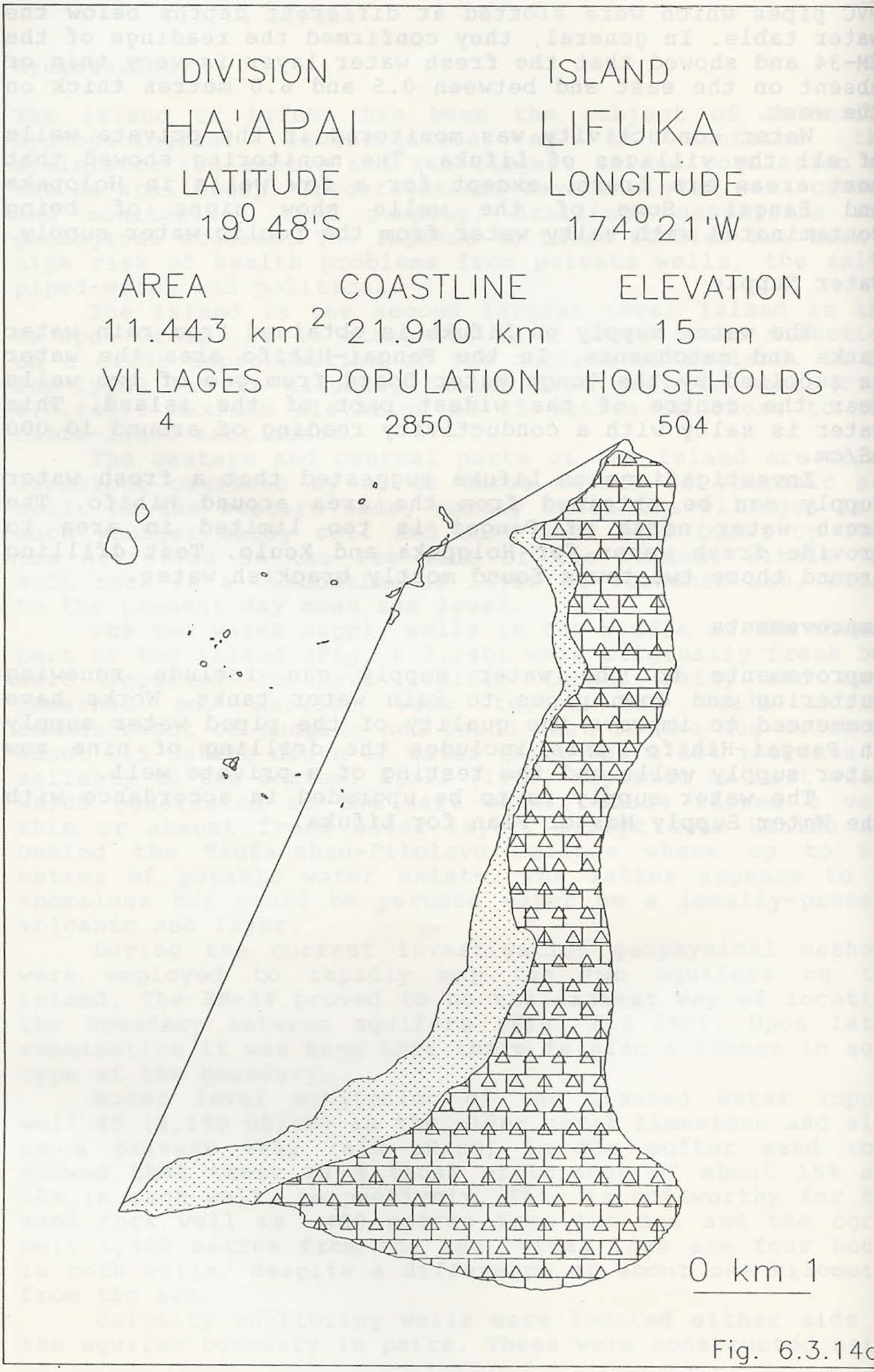
The water supply on Lifuka is obtained from rain water tanks and catchments. In the Pangai-Hihifo area the water is supplied by the Tonga Water Board from one of two wells near the centre of the widest part of the island. This water is salty with a conductivity reading of around 10,000 uS/cm.

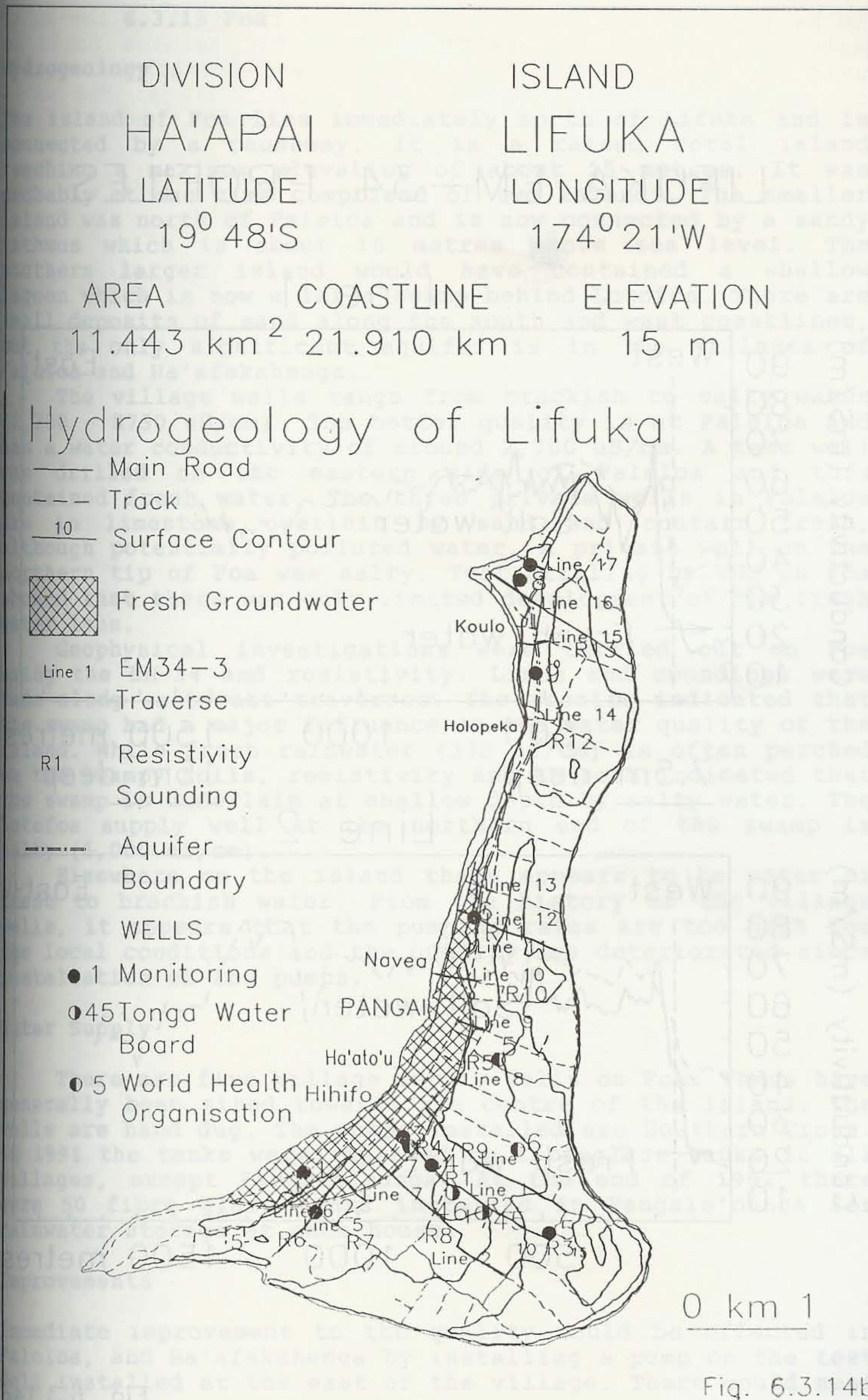
Investigations on Lifuka suggested that a fresh water supply can be obtained from the area around Hihifo. The fresh water north of Pangai is too limited in area to provide fresh water for Holopeka and Koulo. Test drilling around those two towns found mostly brackish water.

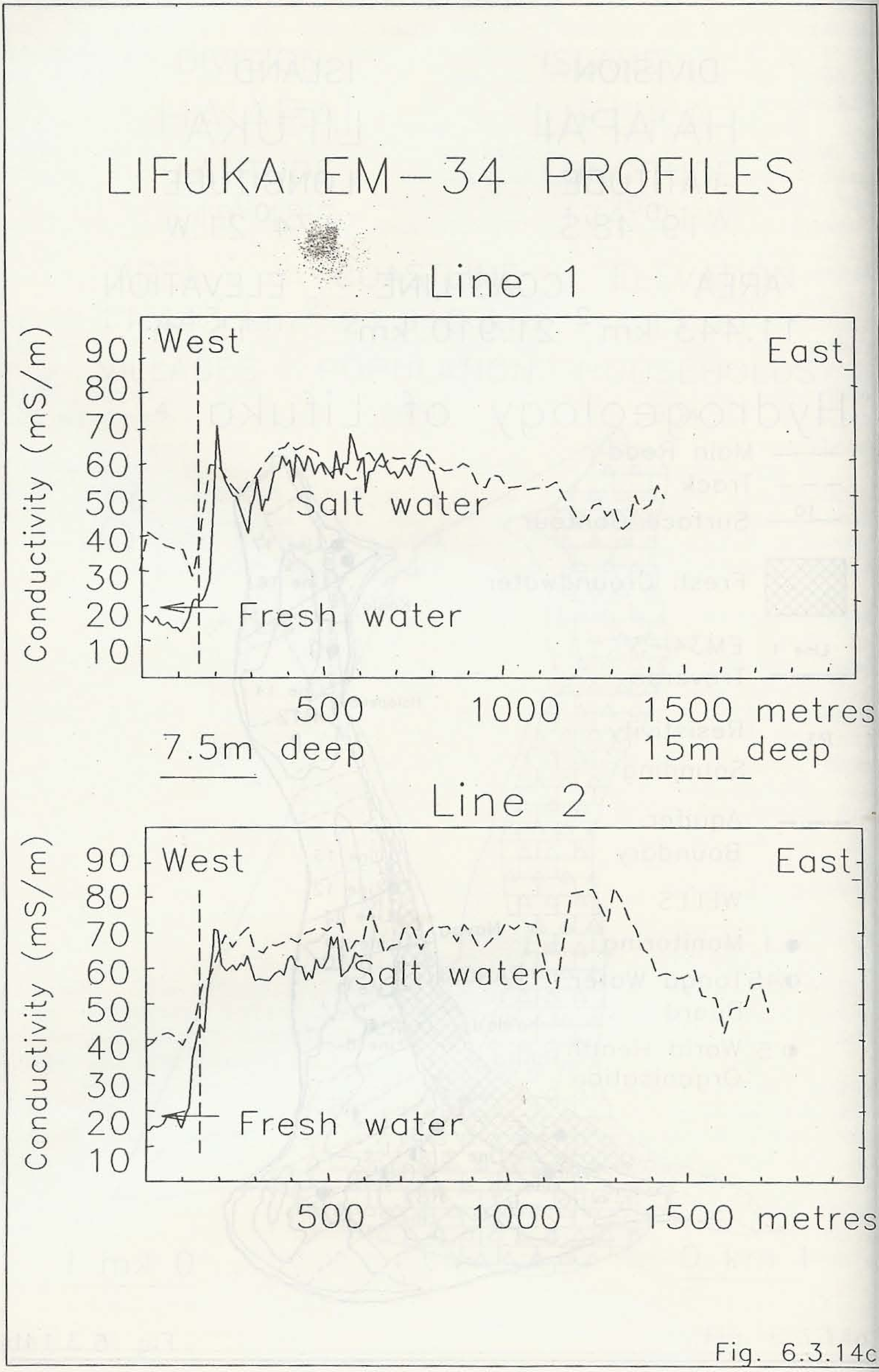
Improvements

Improvements to the water supply can include renewing guttering and down pipes to rain water tanks. Works have commenced to improve the quality of the piped water supply in Pangai-Hihifo. This includes the drilling of nine new water supply wells and the testing of a private well.

The water supply is to be upgraded in accordance with the Water Supply Master Plan for Lifuka.


DIVISION ISLAND
HA'APAI LIFUKA
LATITUDE LONGITUDE
19⁰ 48'S 174⁰21'W
AREA COASTLINE ELEVATION
11.443 km^2 21.910 km 15 m
VILLAGES POPULATION HOUSEHOLDS
4 2850 504
0 km 1
Fig. 6.3.14a


DIVISION
HA'APAI
LATITUDE
19⁰ 48'S
ISLAND
LIFUKA
LONGITUDE
174⁰ 21'W
AREA
11.443 km²
COASTLINE
21.910 km
ELEVATION
15 m
Hydrogeology of Lifuka
Main Road
Track
Surface Contour
Fresh Groundwater
EM34−3 Traverse
Resistivity Sounding
Aquifer Boundary
WELLS
1 Monitoring
45 Tonga Water Board
5 World Health Organisation
Koulo
Holopeka
Navea
PANGAI
Ha'ato'u
Hihifo
Line 17
Line 16
Line 15
Line 14
Line 13
Line 12
Line 10
Line 8
Line 7
Line 6
Line 5
Line 2
R12
R10
R5
R9
R1
R2
R3
R6
R7
R8
0 km 1
Fig. 6.3.14b


LIFUKA EM-34 PROFILES
Line 1
Conductivity (mS/m)
90
80
70
60
50
40
30
20
10
West
East
Salt water
Fresh water
500
1000
1500 metres
7.5m deep
15m deep
Line 2
Conductivity (mS/m)
90
80
70
60
50
40
30
20
10
West
East
Salt water
Fresh water
500
1000
1500 metres
Fig. 6.3.14c

6.3.15 Foa

Hydrogeology

The island of Foa lies immediately north of Lifuka and is connected by a causeway. It is a raised coral island reaching a maximum elevation of about 15 metres. It was probably at one time comprised of two islands. The smaller island was north of Faleloa and is now connected by a sandy isthmus which is about 10 metres above sea level. The southern larger island would have contained a shallow lagoon which is now a large swamp behind Lotofoa. There are small deposits of sand along the south and west coastlines, but the only significant aquifer is in the villages of Faleloa and Ha'afakahenga.

The village wells range from brackish to salty water (2,700 - 8730 uS/cm). The better quality is at Faleloa and has a water conductivity of around 2,700 uS/cm. A test well was drilled on the eastern side of Faleloa and this contained fresh water. The three private wells in Faleloa are in limestone overlain by sand and contain fresh, although potentially polluted water. A private well on the northern tip of Foa was salty. Test drilling by WHO on Foa showed that there was only limited development of the fresh water lens.

Geophysical investigations were carried out on Foa using the EM-34 and resistivity. Lines and soundings were made along east-west traverses. The results indicated that the swamp had a major influence on the water quality of the island. While fresh rainwater (338 uS/cm) is often perched on the swampy soils, resistivity and EM both indicated that the swamp is underlain at shallow depth by salty water. The Lotofoa supply well at the northern end of the swamp is salty (6,000 uS/cm).

Elsewhere on the island there appears to be water of fresh to brackish water. From the history of the village wells, it appears that the pumping rates are too high for the local conditions and the quality has deteriorated since installation of the pumps.

Water Supply

There are five village supply wells on Foa. These have generally been sited towards the centre of the island. The wells are hand dug. The pumps installed are Southern Cross. In 1991 the tanks were replaced by fibreglass tanks in all villages, except Fangale'ounga. At the end of 1992 there were 50 fibre glass tanks installed in Fangale'ounga for rainwater storage at each house.

Improvements

Immediate improvement to the quality could be effected in Faleloa, and Ha'afakahenga by installing a pump on the test well installed at the east of the village. There would need to be pipeline to connect the well to the tank on the south side of Faleloa. The existing well for Faleloa could be used for Lotofoa. For Fangale'ounga and Fotua, there needs to be two new wells drilled for each village. The wells should be equipped with pumps in the range 0.5 to 1.0 l/s.

DIVISION	ISLAND
HA'APAI	FOA

LATITUDE	LONGITUDE
$19^0 45'S$	$174^0 18'W$

AREA	COASTLINE	ELEVATION
13.542 km^2	18.379 km	15 m

VILLAGES	POPULATION	HOUSEHOLDS
Fangale'ounga	287	38
Fotua	243	41
Lotofoa	399	73
Faleloa	413	81
Ha'afakahenga	68	14
Total	1410	247

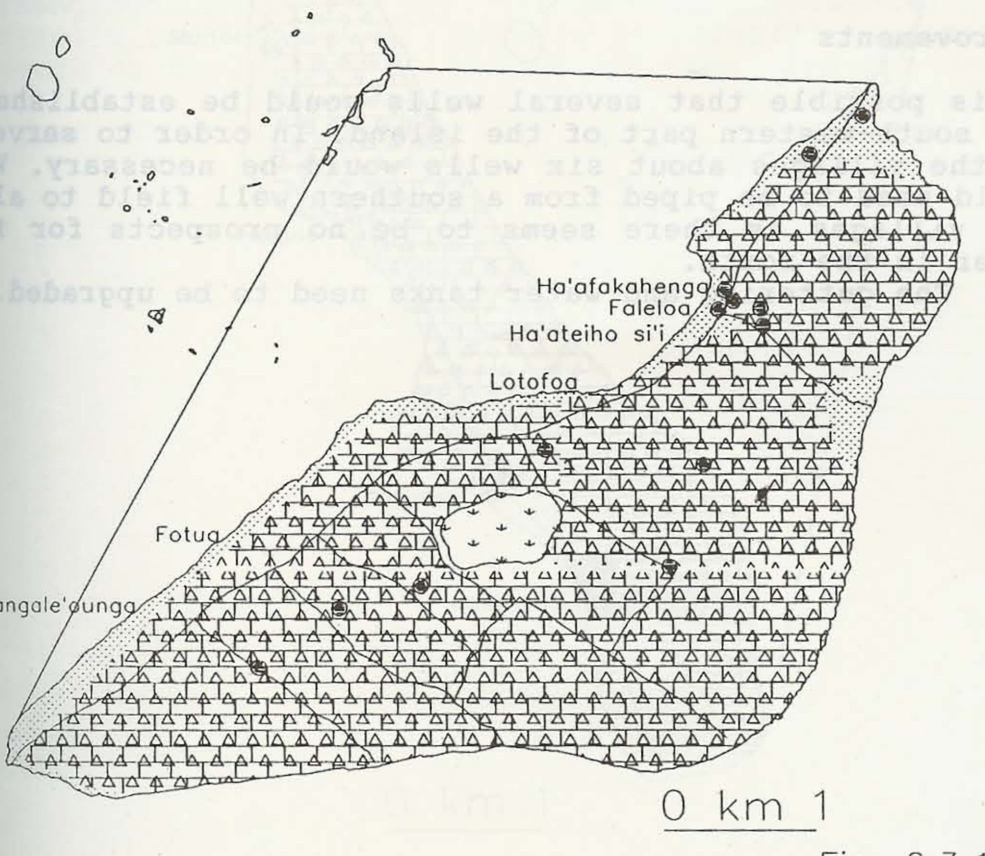


Fig. 6.3.15

6.3.16 Ha'ano

Hydrogeology

The island of Ha'ano was visited in 1991 when a well census and geophysical study was carried out. This island is elongated in a north south direction and is almost flat. It is slightly tilted from east to west. It reaches a maximum elevation of about 10 metres along the eastern coast.

The island is mostly coral limestone with a volcanic ash soil. The south western side of the island has a wedge of younger sediments and a sandy soil. This extends as far northwards as Pukotala and appears to be absent, except for a small sandy area at the extreme north western end of the island near Muitoa.

The well census revealed that there are numerous shallow private wells in Fakakakai and a few in Pukotala. The water was fresh in all but one of the wells. The EM-34 showed fresh water beneath the western part of the island around Fakakakai.

Water Supply

Apart from the private wells in two of the villages, water supply is from rain water tanks and cisterns. Evidence of an ancient water supply well was found on the northern side of Fakakakai.

Improvements

It is possible that several wells could be established on the south-western part of the island. In order to serve all of the villages about six wells would be necessary. Water would need to be piped from a southern well field to all of the villages as there seems to be no prospects for fresh water in the north.

The guttering and water tanks need to be upgraded.

DIVISION	ISLAND	
HA'APAI	HA'ANO	
LATITUDE	LONGITUDE	
19° 40'S	174° 17'W	
AREA	COASTLINE	ELEVATION
6.656 km^2	14.722 km	10 m

VILLAGES	POPULATION	HOUSEHOLDS
Fakakakai	237	40
Pukotala	173	30
Ha'ano	214	46
Muitoa	103	19
Total	727	135

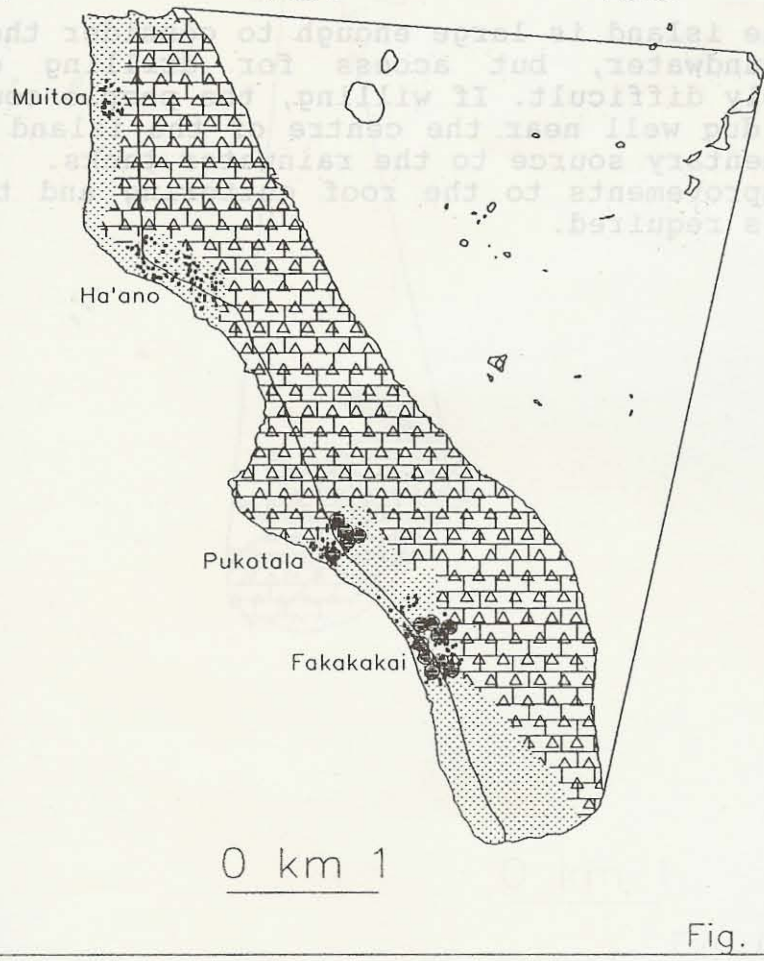


Fig. 6.3.16

6.3.17 Mo'unga'one

Hydrogeology

The island of Mo'unga'one was visited in 1992 when a brief inspection of the water supply was made. The island is roughly circular, mostly of raised coral limestone. It is covered with a volcanic ash soil reaching a maximum elevation of about 15 metres. Reef development is mostly limited to the south east of the island. The rest has a rocky and rugged cliff line. Behind the reef is a thin strip of sand which could possibly be considered as containing a water supply.

It was reported that there was one private well in the bush with salty water, but this was not located during the inspection,

Water Supplies

The water supply is entirely from rain water tanks and catchments. Guttering was found to be extremely limited and in poor condition. During 1992 water supplies were almost exhausted and water was shipped in to the island.

Improvements

The island is large enough to consider the development of groundwater, but access for drilling equipment is extremely difficult. If willing, the people could construct a hand dug well near the centre of the island to provide a supplementary source to the rainwater tanks.

Improvements to the roof guttering and the number of tanks is required.

DIVISION	ISLAND
HA'APAI	MO'UNGA'ONE
LATITUDE	LONGITUDE
19^{0} 38'S	174^{0} 29'W

AREA	COASTLINE	ELEVATION
1.384 km^2	5.714 km	15 m
VILLAGES	POPULATION	HOUSEHOLDS
Mo'unga'one	164	38

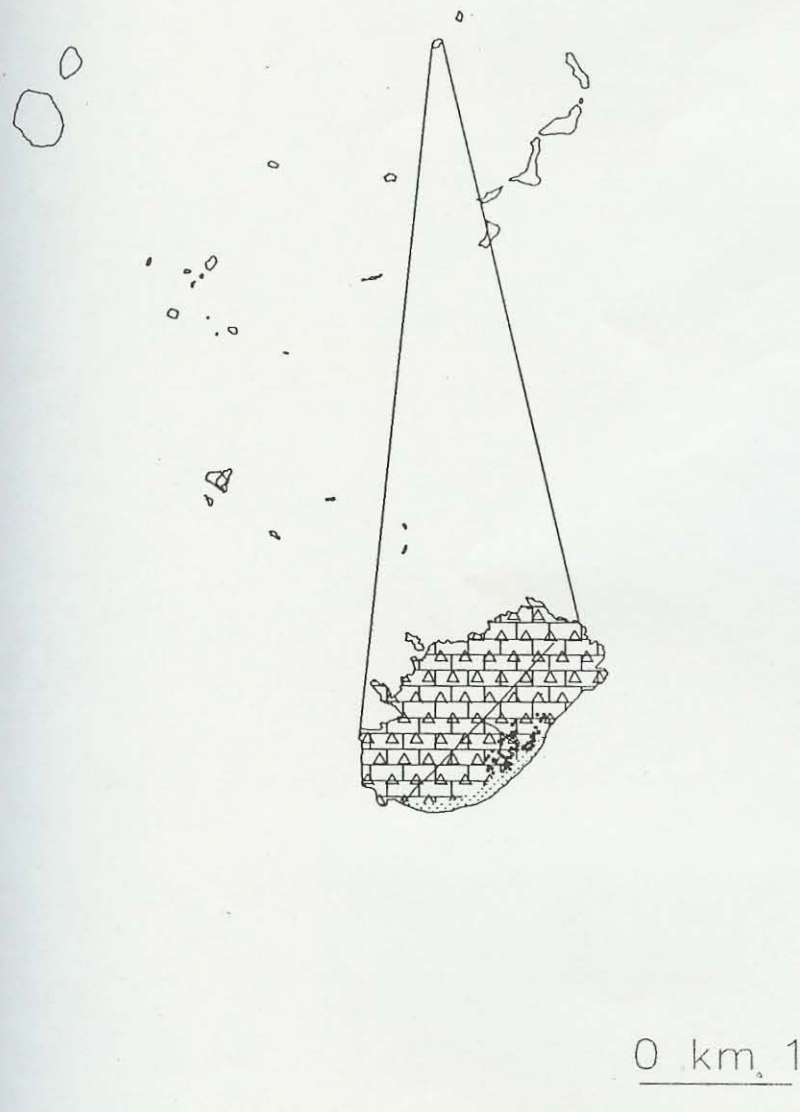


Fig. 6.3.17

6.4 Vava'u Group

6.4 Vava'u Group

6.4.1 Description

The Vava'u Group lies approximately 200 km to the north of Tongatapu. Vava'u is characterised by uplifted coral islands with a general southerly dip. The main island has a complex shape with several deep inlets. There are high and steep cliffs rising up to 200 metres from the sea. There are many small islands close to the south and east of the main island. Some of the islands are joined to the main islands by causeways.

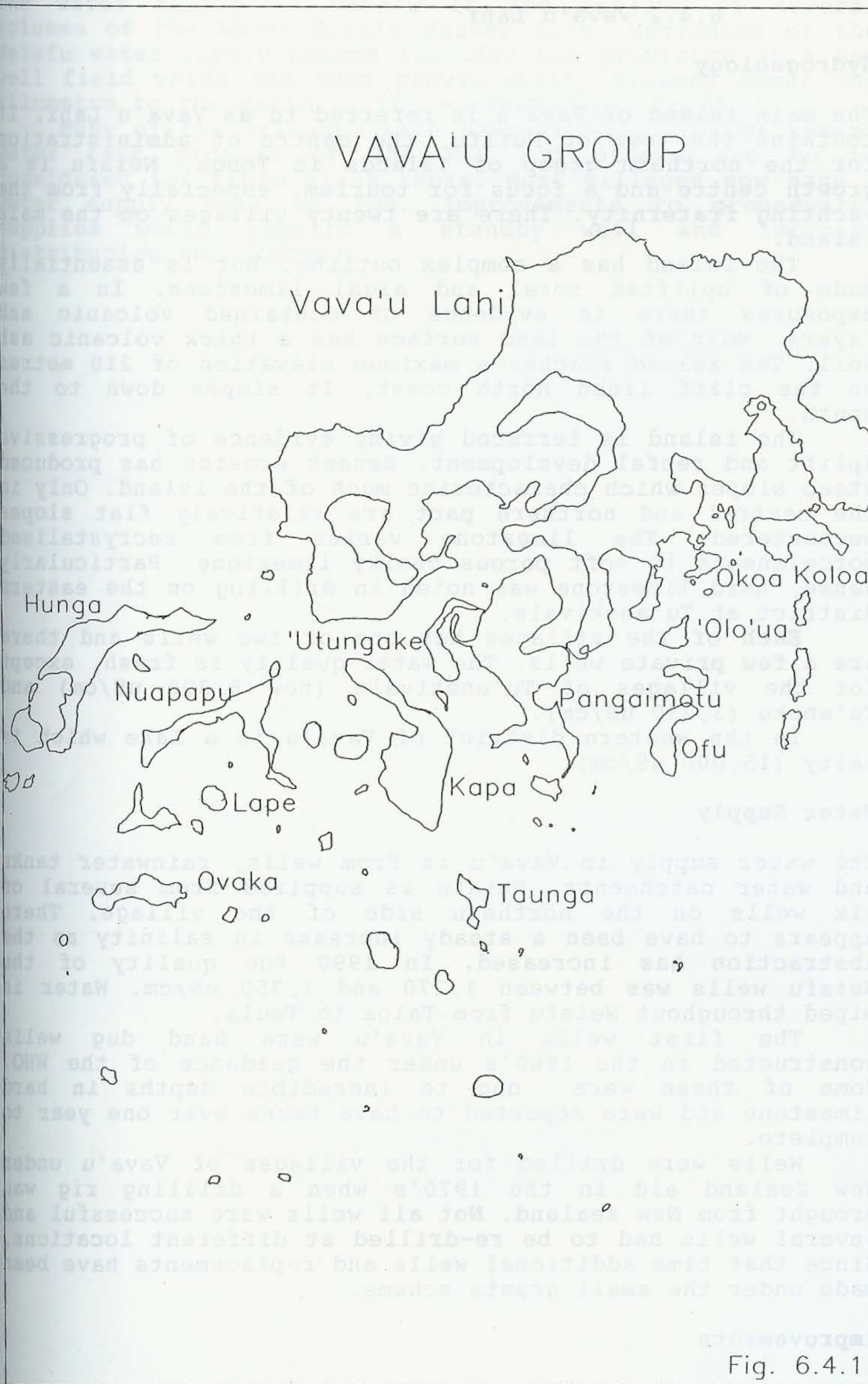

VAVA'U GROUP
Vava'u Lahi
Okoa Koloa
Hunga
'Olo'ua
'Utungake
Nuapapu
Pangaimotu
Ofu
Kapa
Lape
Ovaka
Taunga

Fig. 6.4.1

6.4.2 Vava'u Lahi

Hydrogeology

The main island of Vava'u is referred to as Vava'u Lahi. It contains the town of Neiafu, the centre of administration for the northern group of islands in Tonga. Neiafu is a growth centre and a focus for tourism, especially from the yachting fraternity. There are twenty villages on the main island.

The island has a complex outline, but is essentially made of uplifted coral and algal limestone. In a few exposures there is evidence of contained volcanic ash layers. Most of the land surface has a thick volcanic ash soil. The island reaches a maximum elevation of 210 metres on the cliff lined north coast. It slopes down to the south.

The island is terraced giving evidence of progressive uplift and reefal development. Recent erosion has produced steep slopes which characterise much of the island. Only in the central and northern part are relatively flat slopes encountered. The limestone varies from recrystalised porcelaneous to soft porous chalky limestone. Particularly dense, hard limestone was noted in drilling on the eastern district at Tu'anekivale.

Each of the villages has one or two wells and there are a few private wells. The water quality is fresh, except for the villages of Tu'anekivale (now 6,300 uS/cm) and Tu'anuku (3,230 uS/cm).

In the western district of Vava'u is a lake which is salty (15,000 uS/cm).

Water Supply

The water supply in Vava'u is from wells, rainwater tanks and water catchments. Neiafu is supplied from several of six wells on the northern side of the village. There appears to have been a steady increase in salinity as the abstraction has increased. In 1990 the quality of the Neiafu wells was between 1,270 and 1,750 uS/cm. Water is piped throughout Neiafu from Taloa to Toula.

The first wells in Vava'u were hand dug wells constructed in the 1960's under the guidance of the WHO. Some of these were dug to incredible depths in hard limestone and were reported to have taken over one year to complete.

Wells were drilled for the villages of Vava'u under New Zealand aid in the 1970's when a drilling rig was brought from New Zealand. Not all wells were successful and several wells had to be re-drilled at different locations. Since that time additional wells and replacements have been made under the small grants scheme.

Improvements

The water supply in Vava'u is the subject of several volumes of the Water Supply Master Plan. Upgrading of the Neiafu water supply scheme includes the provision of a new well field which has been provisionally planned about one kilometre to the north of the existing well field.

Many of the villages have been included in the cement water tank program of the FSP and others are to be considered for fibre glass tanks. Most villages now have a water supply well or two. Improvements to groundwater supplies would require a standby well and improved distribution and storage.

DIVISION	ISLAND	
VAVA'U	VAVA'U	
LATITUDE	LONGITUDE	
18^{0} 39'S	173^{0} 59'W	
AREA	COASTLINE	ELEVATION
92.423 km^{2}	106.113 km	210 m
VILLAGES	POPULATION	HOUSEHOLDS
19	11680	1928

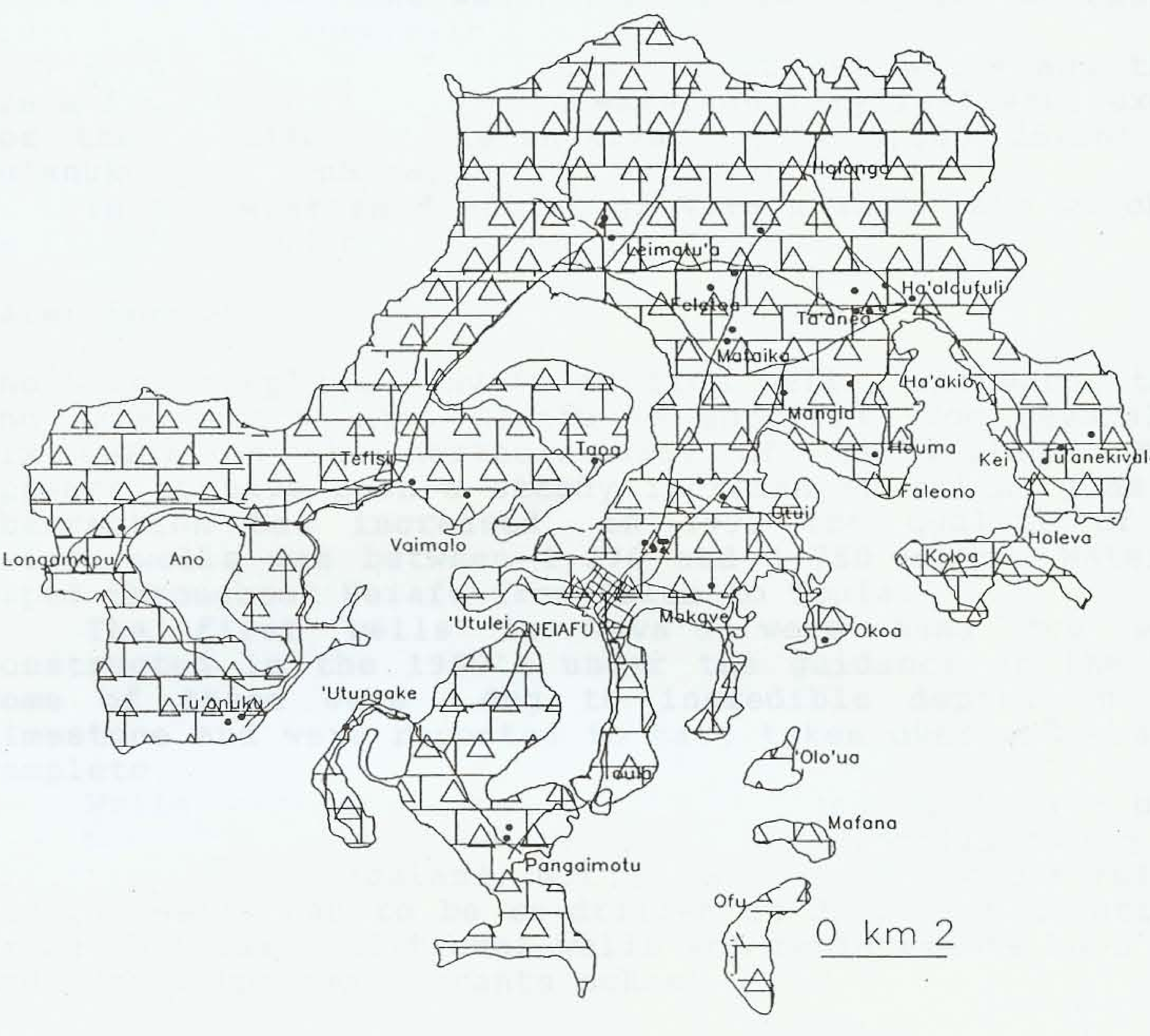


Fig. 6.4.2

6.4.3 Pangaimotu

Hydrogeology

Pangaimotu lies to the immediate south of Neiafu and is connected to the main island with a short causeway across a shallow inlet. It has a complex shape and a hilly profile. The maximum elevation is 60 metres above sea level. As with Vava'u Lahi it is made of uplifted coral limestone with a volcanic ash soil.

At the village of Pangai there are two wells in close proximity with reasonable quality water (1,120 uS/cm).

Water Supply

Water supply on Pangaimotu is obtained from rainwater tanks and catchments and two wells in Pangai. 'Utulei does not have a well.

Improvements

The water supply of Pangaimotu can be improved by additional rainwater tanks, improvements to guttering and a new well at 'Utulei. The well should be drilled approximately one kilometre to the south of 'Utulei at the road bend.

DIVISION		ISLAND
VAVA'U		PANGAIMOTU
LATITUDE		LONGITUDE
18^{0} 41'S		174^{0} 00'W
AREA	COASTLINE	ELEVATION
9.044 km^2	23.379 km	60 m
VILLAGES	POPULATION	HOUSEHOLDS
Pangaimotu	659	101
'Utulei	159	29
Total	818	130

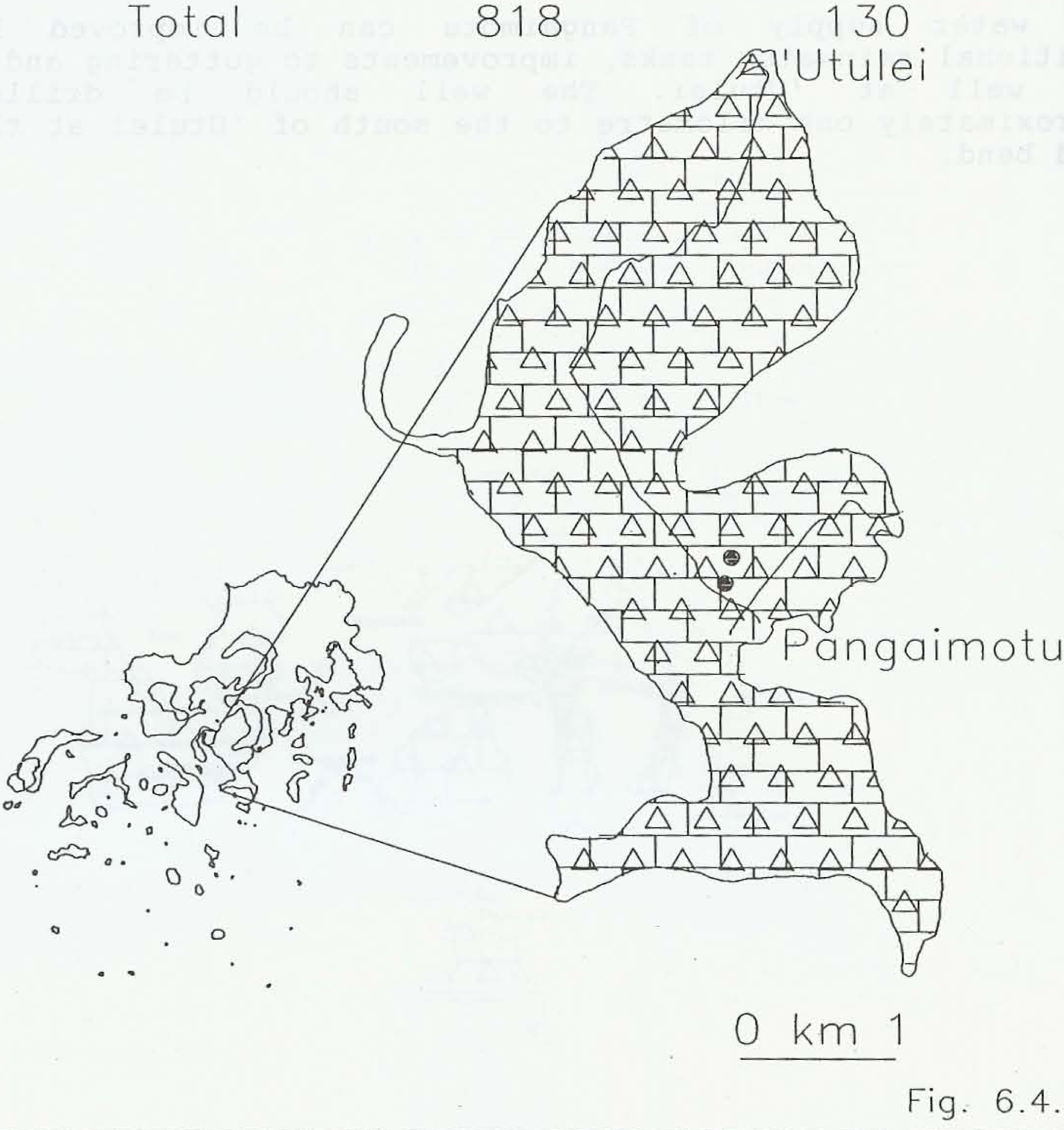


Fig. 6.4.3

6.4.4 Kapa

Hydrogeology

Kapa is south of Pangaimotu and accessed from the main island by boat. It contains three villages on different sides of the island. The island has a complex shape and is mostly steep slopes, except for the western and northern shores around the villages. The maximum elevation is 90 metres above sea level.

The island is formed from uplifted coral limestone with a volcanic ash soil on the flatter slopes. Around the villages on the west and north is a small area of sandy soils.

The village of Falevai has a dug well which was fresh when first constructed, but which turned salty with over pumping. At the time of inspection the water was fresh again (920 uS/cm). In the northern village of 'Otea are a few hand dug wells constructed in sand which are fresh (700, 780 uS/cm).

Water Supply

The water supply on Kapa is obtained mainly from rain water tanks, catchments and a few private wells. The well in Falevai has not been used for a long time.

Improvements

The water supply can be improved by additional rain water tanks, improvement to roof guttering and renovating the well at Falevai. This well should be re-equipped with a much smaller pump. It is recommended that a geophysical survey be made with the EM equipment to locate an alternative well site.

Access to the other villages of Kapa for a drilling rig is practically impossible and the high terrain rules out suitable drilling sites.

DIVISION	ISLAND
VAVA'U	KAPA
LATITUDE	LONGITUDE
18^0 42'S	174^0 02'W

AREA	COASTLINE	ELEVATION
6.153 km^2	14.958 km	90 m

VILLAGES	POPULATION	HOUSEHOLDS
Kapa	90	25
Falevai	179	38
'Otea	162	27
Total	431	90

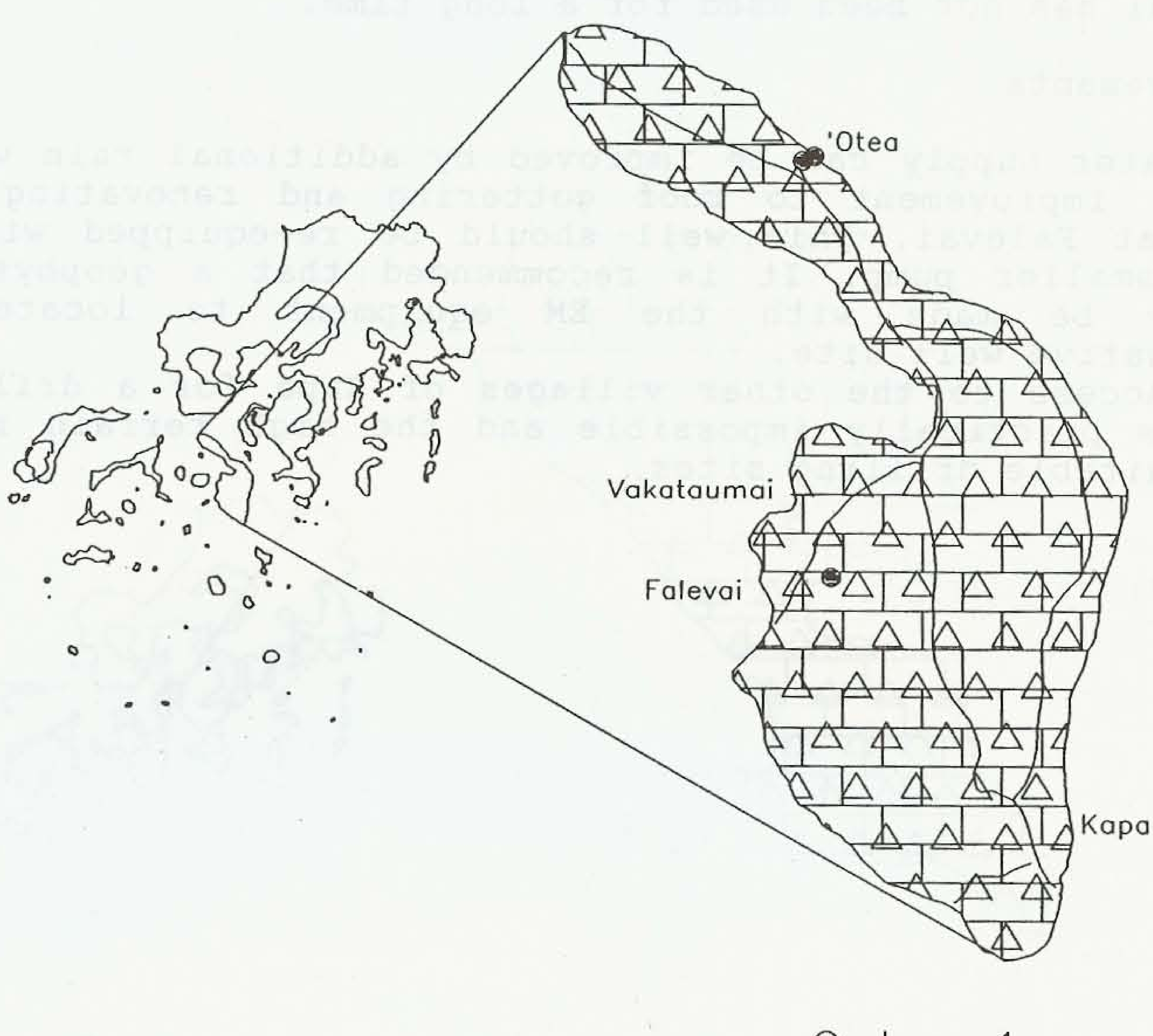


Fig. 6.4.4

6.4.5 'Utangake

Hydrogeology

'Utungake was visited in 1991 to inspect a recently dug well at the Tongan Beach Resort. This is a narrow crescent shaped island connected to Pangaimotu by causeway. The thin island contains two villages on an uplifted coral limestone (maximum elevation 80 m) with a volcanic ash soil.

At the Tongan Beach Resort a shallow well was dug in sand. The water was slightly salty (2,900 uS/cm).

Water Supply

Rainwater tanks and catchments are used on the island.

Improvements

Improvements to the water supply can only come from increased rainwater tanks and roof guttering. There is little scope for groundwater development considering the width of the island. In the future the possibility of piping groundwater from Pangaimotu is a better option. This may be practical when the well for 'Utulei is constructed.

DIVISION	ISLAND
VAVA'U	'UTUNGAKE
LATITUDE	LONGITUDE
18^{0} 40'S	174^{0} 01'W

AREA	COASTLINE	ELEVATION
1.051 km^2	7.444 km	80 m

VILLAGES	POPULATION	HOUSEHOLDS
'Utanangake	253	47
Nga'unoho	176	28
Total	429	75

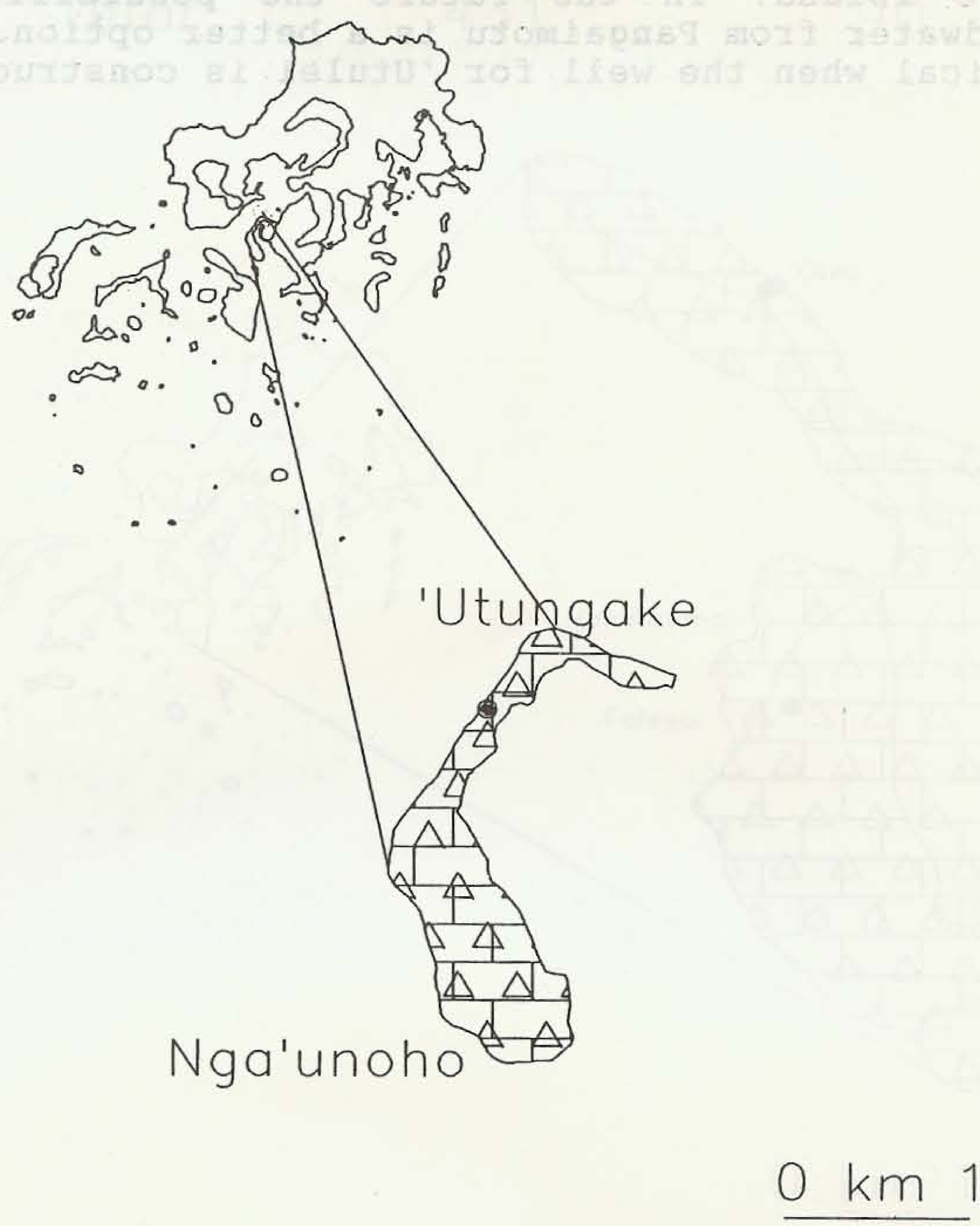


Fig. 6.4.5

6.4.6 Nuapapu

Hydrogeology

Nuapapu was visited in 1990 when the water supply was inspected. It is a narrow elongated island reaching a maximum elevation of 50 metres. It is a raised limestone island with a volcanic ash soil. In the village of Matamaka is a small sandy spit connecting the two rocky parts of the island.

In Matamaka one shallow hand dug well containing fresh water (540 uS/cm) was inspected.

Water Supply

The two villages rely on rain water tanks and catchments. In recent years the island has been part of the FSP cement tank program.

Improvements

The only improvements which can be considered are an increase in rain water tanks and improvement to guttering. There is virtually no scope for groundwater development given the narrow width and difficult access for equipment to the island.

DIVISION		ISLAND
VAVA'U		NUAPAPU
LATITUDE		LONGITUDE
18^0 42'S		174^0 05'W
AREA	COASTLINE	ELEVATION
2.786 km^2	16.182 km	50 m
VILLAGES	POPULATION	HOUSEHOLDS
Nuapapu	177	37
Matamaka	187	35
Total	364	72

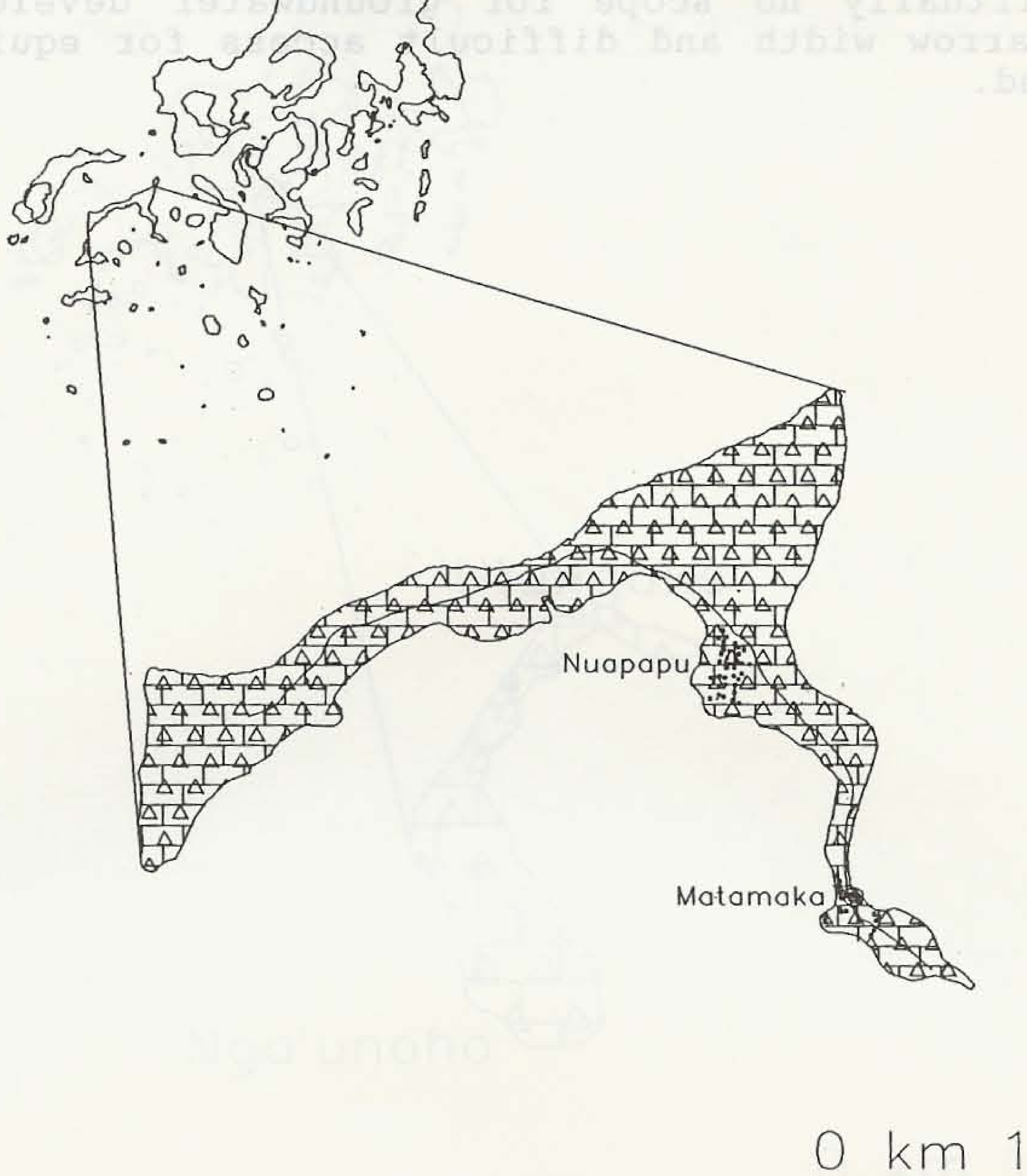


Fig. 6.4.6

6.4.7 Hunga

Hydrogeology

Hunga is an elongated and elevated coral limestone island. It reaches a maximum elevation of 90 metres. It was visited in 1990 to inspect the water supply facilities. Groundwater discharge into the lagoon was observed.

Water Supply

Rain water tanks and catchments are the only sources of water on the island. There are no wells.

Improvements

Possible improvements to the water supply include increasing the number of rainwater tanks and guttering. A well should be drilled at the back of the village as Hunga is considered large enough to support a groundwater lens.

Access to the village needs to be improved by barging a bulldozer in to the lagoon and improving the track to the village. Once this is achieved a well can be drilled on the north west side in the slight depression.

DIVISION VAVA'U

ISLAND HUNGA

LATITUDE 18^{0} 41'S

LONGITUDE 174^{0} 07'W

AREA	COASTLINE	ELEVATION
5.225 km^2	18.739 km	90 m

VILLAGES	POPULATION	HOUSEHOLDS
Hunga	343	69

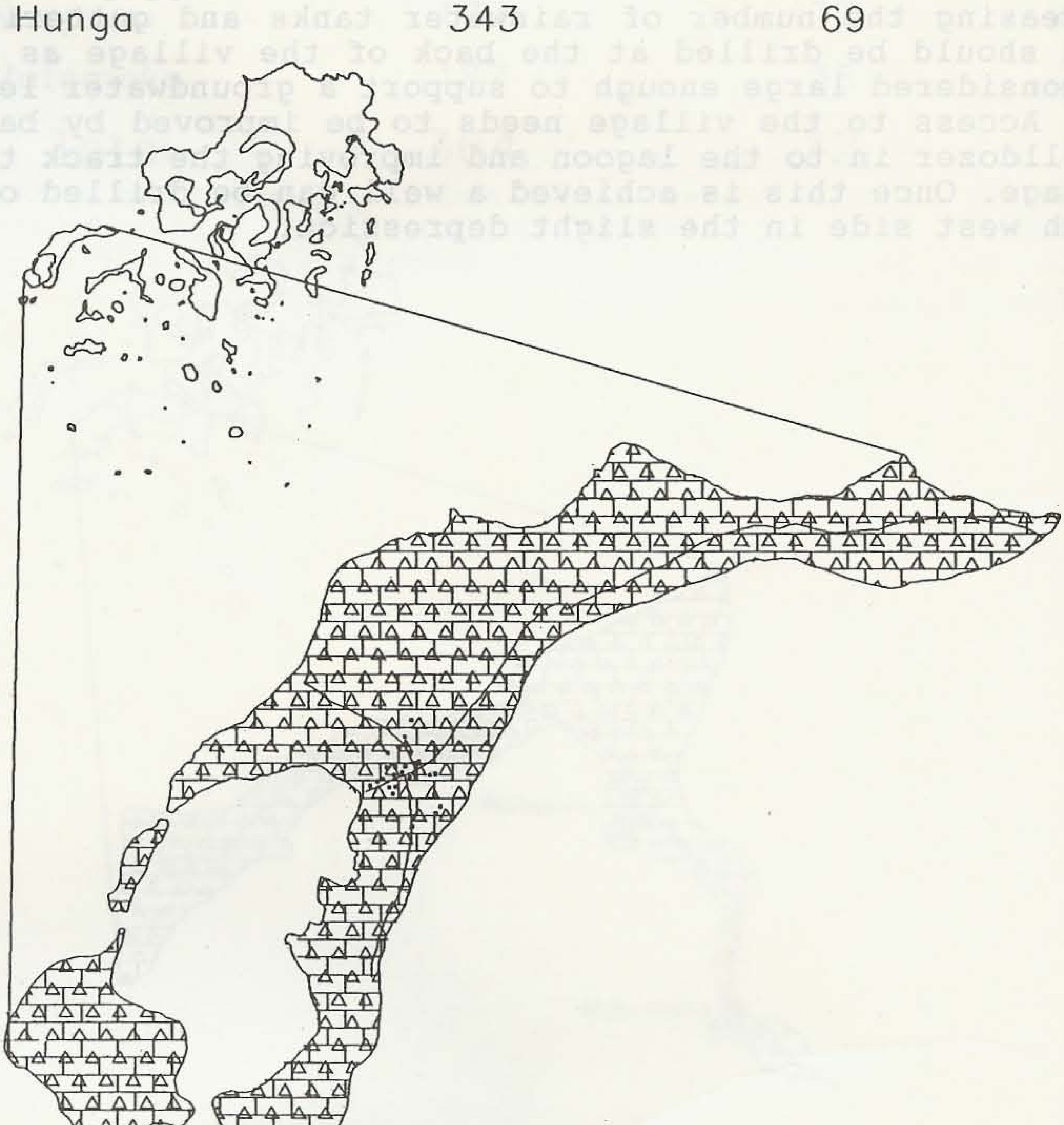


Fig. 6.4.7

6.4.8 'Okoa

Hydrogeology

A hydrogeological inspection and test drilling were carried out on 'Okoa in 1991. The island is almost circular and relatively flat, being only 20 metres above sea level. It is connected to Vava'u Lahi by a causeway.

Investigations were made at the request of the Ministry of Health into the prospects of a water supply for the village. An initial inspection revealed that the island is an uplifted coral limestone with a volcanic ash soil. Near the centre of the island is a depression containing a swamp.

Geophysical studies were made using the EM-34. The results indicated that the groundwater in the vicinity of the swamp was salty. The swamp itself was fresh (247 uS/cm). Between the swamp and the eastern coast there was an indication that the groundwater was fresher in a narrow zone.

Test drilling at the point of lowest conductivity showed that the groundwater was salty (10,800 uS/cm) and would not be useful for a village water supply.

Water Supply

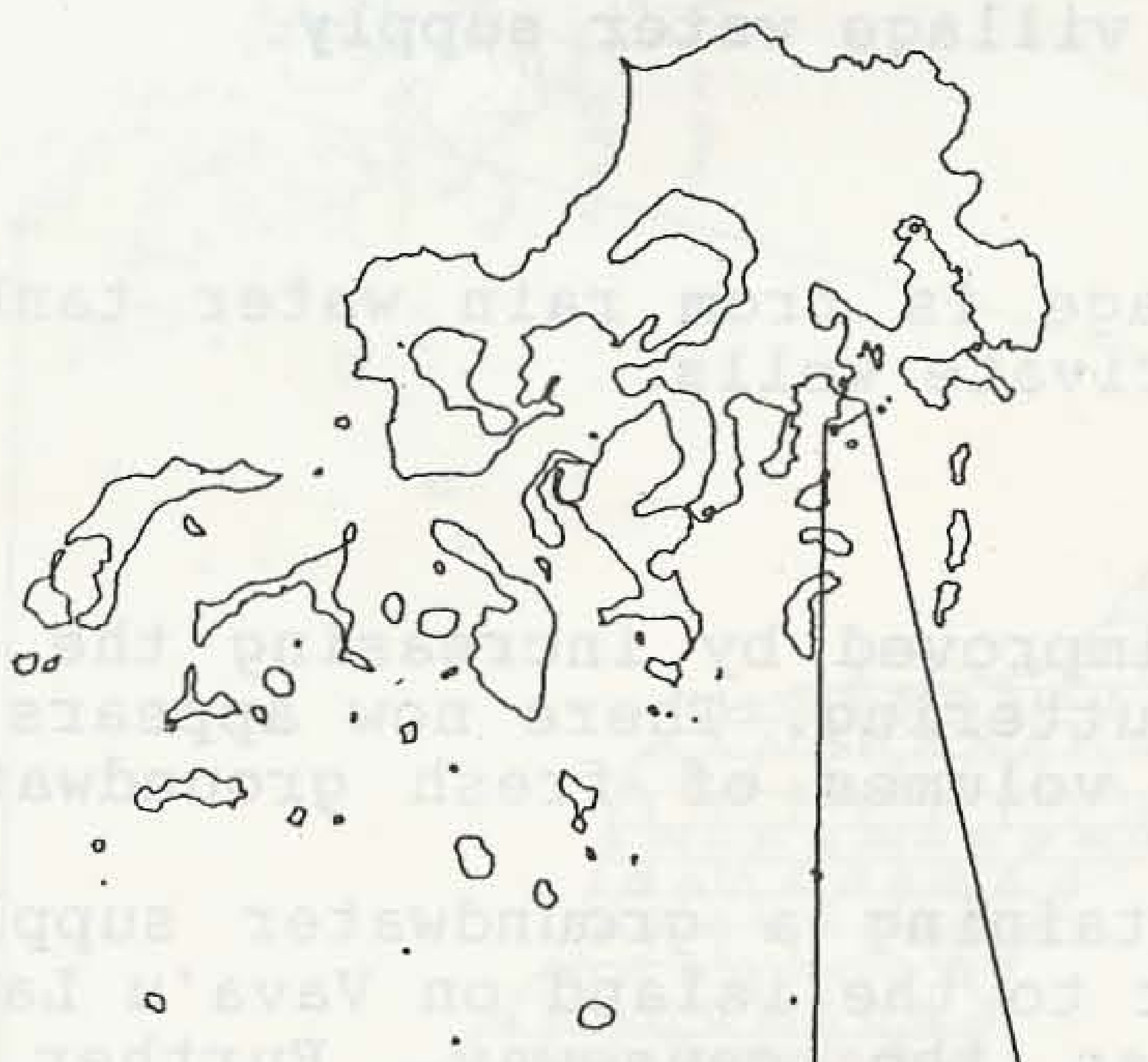
Water supply to the village is from rain water tanks and catchment. There are no private wells.

Improvements

The water supply can be improved by increasing the number of rain water tanks and guttering. There now appears to be no chance of significant volumes of fresh groundwater on the island.

The next step in obtaining a groundwater supply for 'Okoa is to drill adjacent to the island on Vava'u Lahi and to pipe the water across the causeway. Further EM-34 studies need to be made to identify the source of the fresh water.

DIVISION	ISLAND	
VAVA'U	OKOA	
LATITUDE	LONGITUDE	
18^0 39'S	173^0 57'W	
AREA	COASTLINE	ELEVATION
0.450 km^2	3.077 km	20 m
VILLAGES	POPULATION	HOUSEHOLDS
Okoa	232	34



0 km 1

Fig. 6.4.8

6.4.9 Ofu

Hydrogeology

The small island of Ofu was inspected in 1991 with the requirement to locate a water supply for a proposed resort. It is a relatively flat island reaching only 30 metres above sea level. Limestone is observed on the northern and southern parts of the island. There is only limited volcanic ash soil with the area around the village being mostly a sand spit.

In the village several private wells were tested and found to be fresh (578, 653 uS/cm). Behind the village is a swamp with fresh water. An ancient vaitupu was seen south of the village with fresh water.

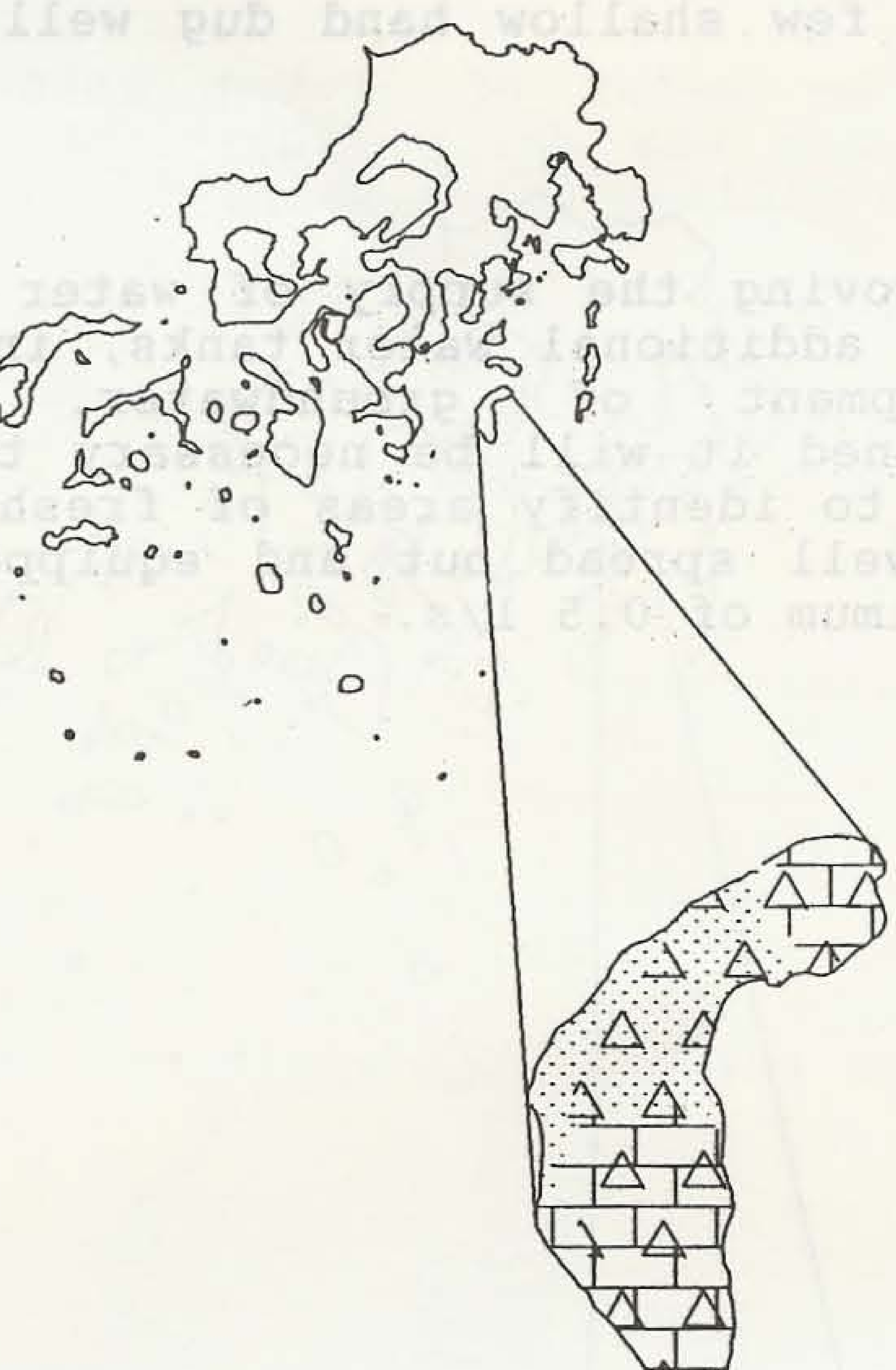
Water Supply

The village obtains water from rain water tanks and catchments. There are a few shallow hand dug wells which contain fresh water.

Improvements

There is scope for improving the supply of water on Ofu through the provision of additional water tanks, increased guttering and development of groundwater. Before groundwater can be obtained it will be necessary to carry out a geophysical study to identify areas of fresh water. Wells will need to be well spread out and equipped with pumps operating at a maximum of 0.5 l/s.

DIVISION		ISLAND
VAVA'U		OFU
LATITUDE		LONGITUDE
$18^{0}42'S$		$173^{0}58'W$
AREA	COASTLINE	ELEVATION
$1.373\ km^2$	6.044 km	30 m
VILLAGES	POPULATION	HOUSEHOLDS
Ofu	218	36



0 km 1

Fig. 6.4.9

6.4.10 Taunga

Hydrogeology

Taunga is a small island comprising a circular elevated limestone hill, an elongated sand spit and a smaller circular hill. The maximum elevation of the hill is 40 metres above sea level. On the elevated parts of the island there is a volcanic ash soil, elsewhere there is sand.

One well is reported to exist in the village but is said to be salty.

Water Supply

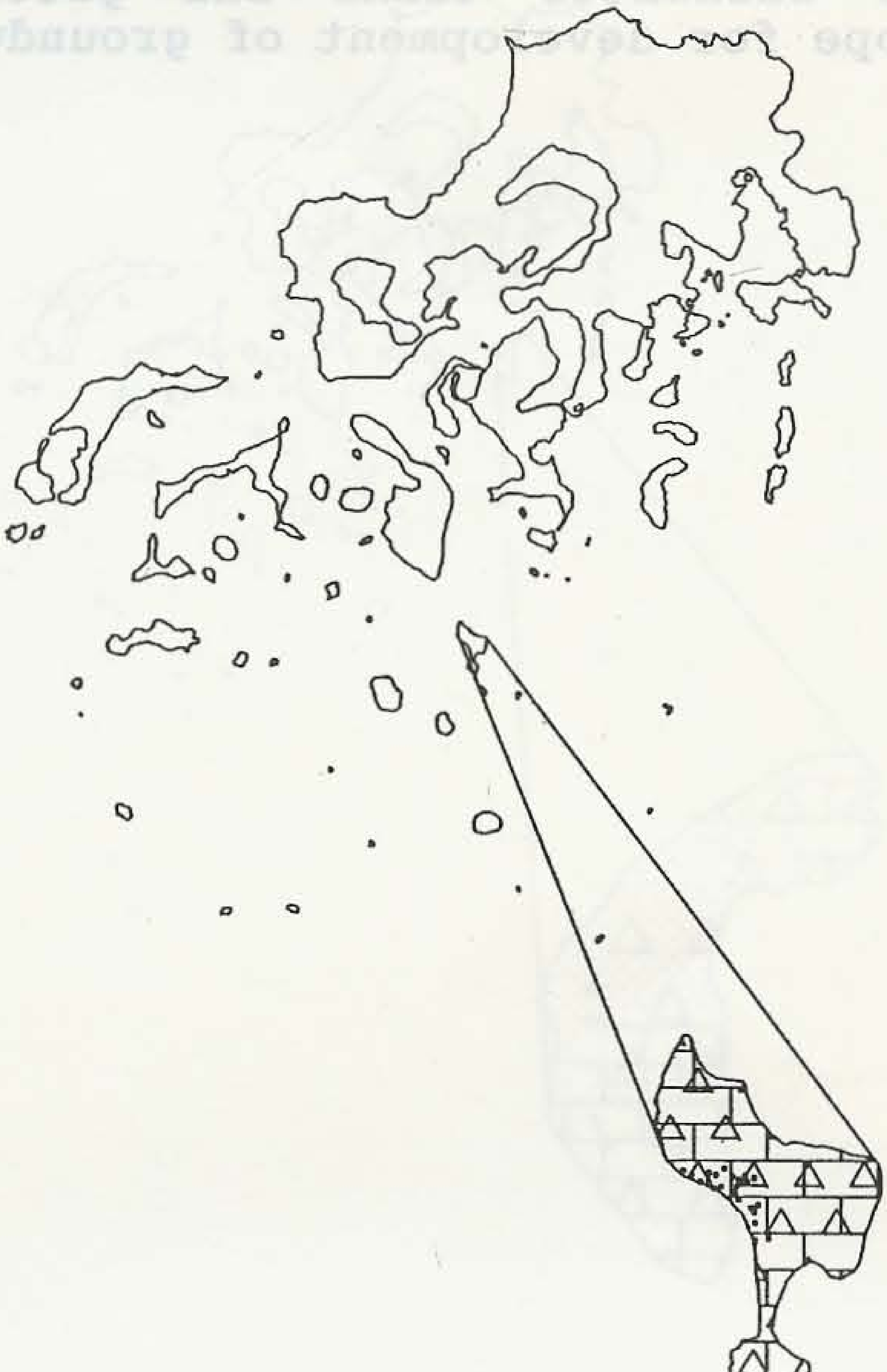
The water supply is from rain water tanks and catchments.

Improvements

The only improvements to water supply could be in the form of increased numbers of rainwater tanks and guttering. There is virtually no scope for development of groundwater.

DIVISION	ISLAND
VAVA'U	TAUNGA
LATITUDE	LONGITUDE
18^{0} 45'S	174^{0} 01'W

AREA	COASTLINE	ELEVATION
0.565 km ^{2}	4.717 km	40 m
VILLAGES	POPULATION	HOUSEHOLDS
Taunga	107	21



0 km 1

Fig. 6.4.10

6.4.11 'Olo'ua

Hydrogeology

'Olo'ua is a small island, nearly circular, consisting of raised coral limestone with a volcanic ash. It reaches a maximum altitude of 30 metres above sea level. There are no known wells on the island.

Water Supply

The water supply is from rain water and catchments.

Improvements

Improvement of water supply can be from increased numbers of tanks and roof guttering. A geophysical study is required to assess the possibility of locating fresh groundwater on the island.

DIVISION	ISLAND
VAVA'U	'OLO'UA
LATITUDE	LONGITUDE
18^0 40'S	173^0 57'W

AREA	COASTLINE	ELEVATION
0.492 km^2	3.299 km	30 m

VILLAGES	POPULATION	HOUSEHOLDS
'Olo'ua	94	17

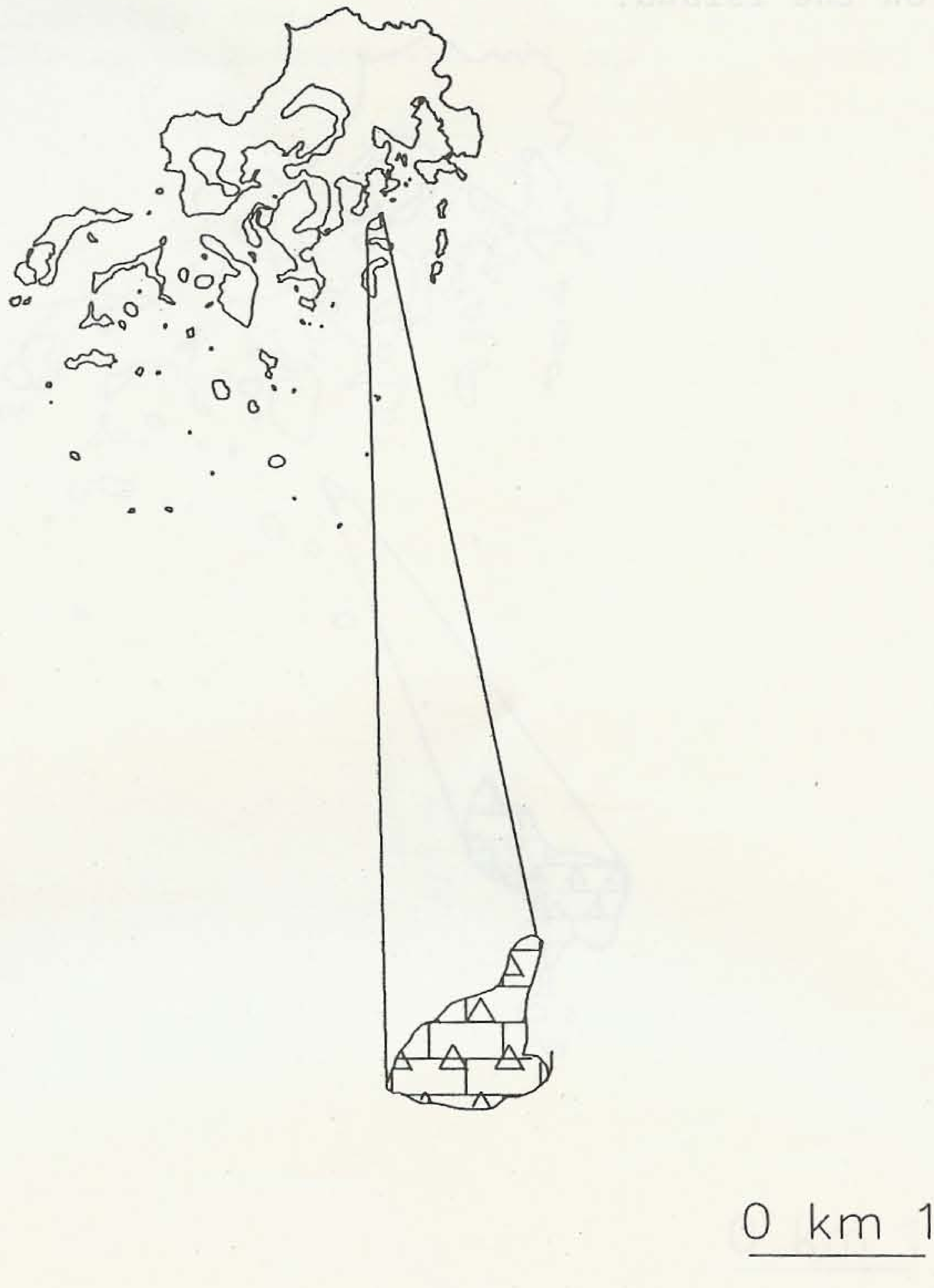


Fig. 6.4.11

6.4.12 Koloa

Hydrogeology

Koloa is a small island at the eastern end of Vava'u Lahi which is reached by causeway from Tu'anekivale. It is roughly circular in outline and reaches a maximum elevation of 30 metres above sea level. It is a raised coral limestone with a volcanic ash soil. There are no wells on the island. The island was visited in 1990.

Water Supply

The water supply of the two villages on the island is from rain water tanks and catchments.

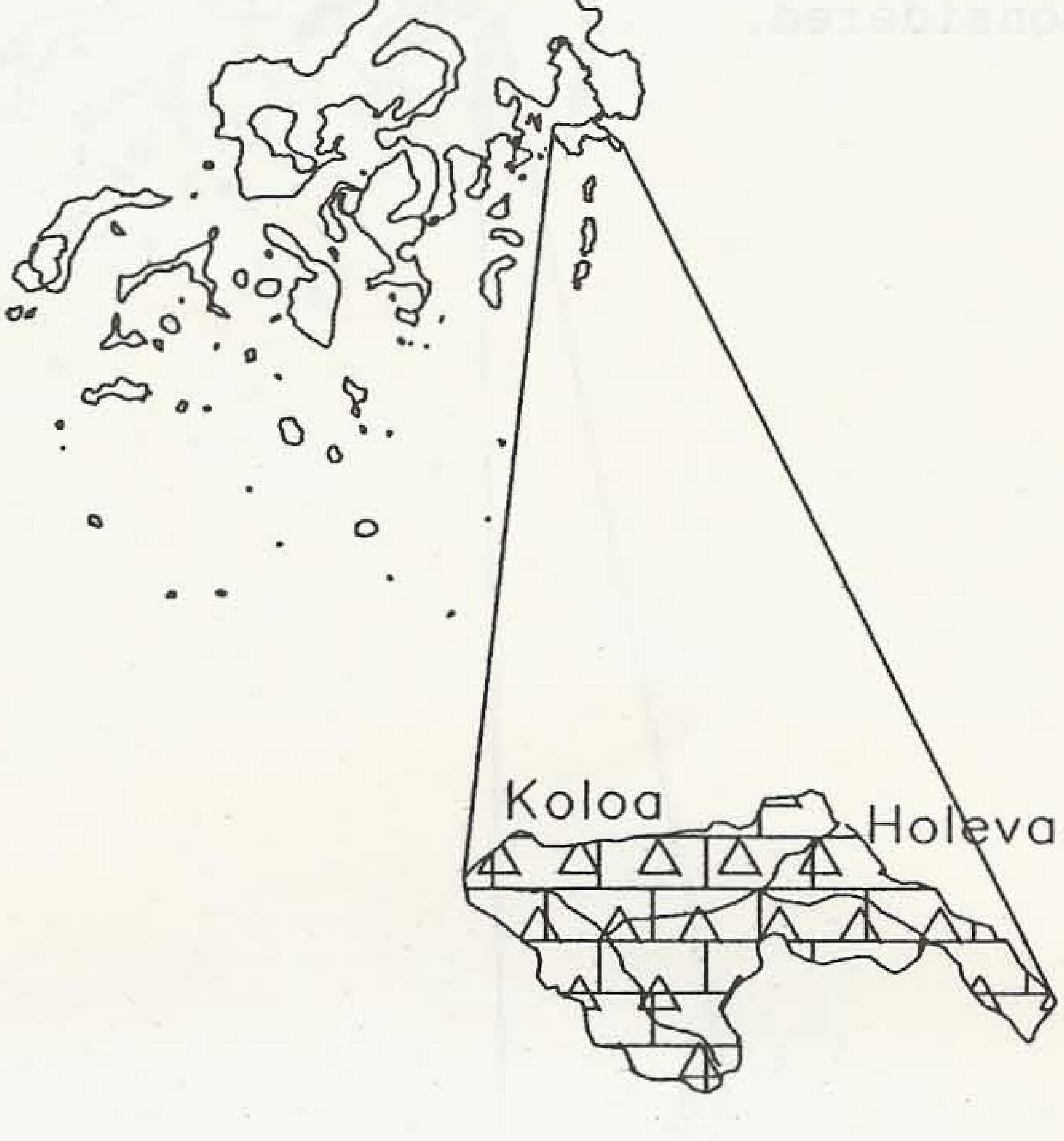
Improvements

The supplies of water can be improved by increasing the number of tanks and roof guttering. The island is possibly large enough to support a fresh water lens. This needs an investigation using the EM-34 equipment. Should this fail to indicate a source of fresh groundwater then the possibility of piping water from a well in the vicinity of Ta'anea should be considered.

DIVISION	ISLAND
VAVA'U	KOLOA
LATITUDE	LONGITUDE
$18^{0}39'S$	$173^{0}56'W$

AREA	COASTLINE	ELEVATION
1.310 km^2	6.608 km	30 m

VILLAGES	POPULATION	HOUSEHOLDS
Koloa	193	28
Holeva	127	16
Total	320	44



0 km 1

Fig. 6.4.12

6.4.13 Lape

Hydrogeology

Lape is a small island which appears to be part of the structure containing Nuapapu. It is a raised coral island with a volcanic ash soil reaching a maximum elevation of 20 metres above sea level. There are no wells on the island.

Water Supply

The water supply is from rain water and catchments.

Improvements

The only improvement to suggest is rain water tanks and improved guttering. There is little chance of developing groundwater on such a small island.

DIVISION		ISLAND
VAVA'U		LAPE
LATITUDE		LONGITUDE
18^0 43'S		174^0 05'W
AREA	COASTLINE	ELEVATION
0.383 km ^{2}	2.331 km	20 m
VILLAGES	POPULATION	HOUSEHOLDS
Lape	26	7

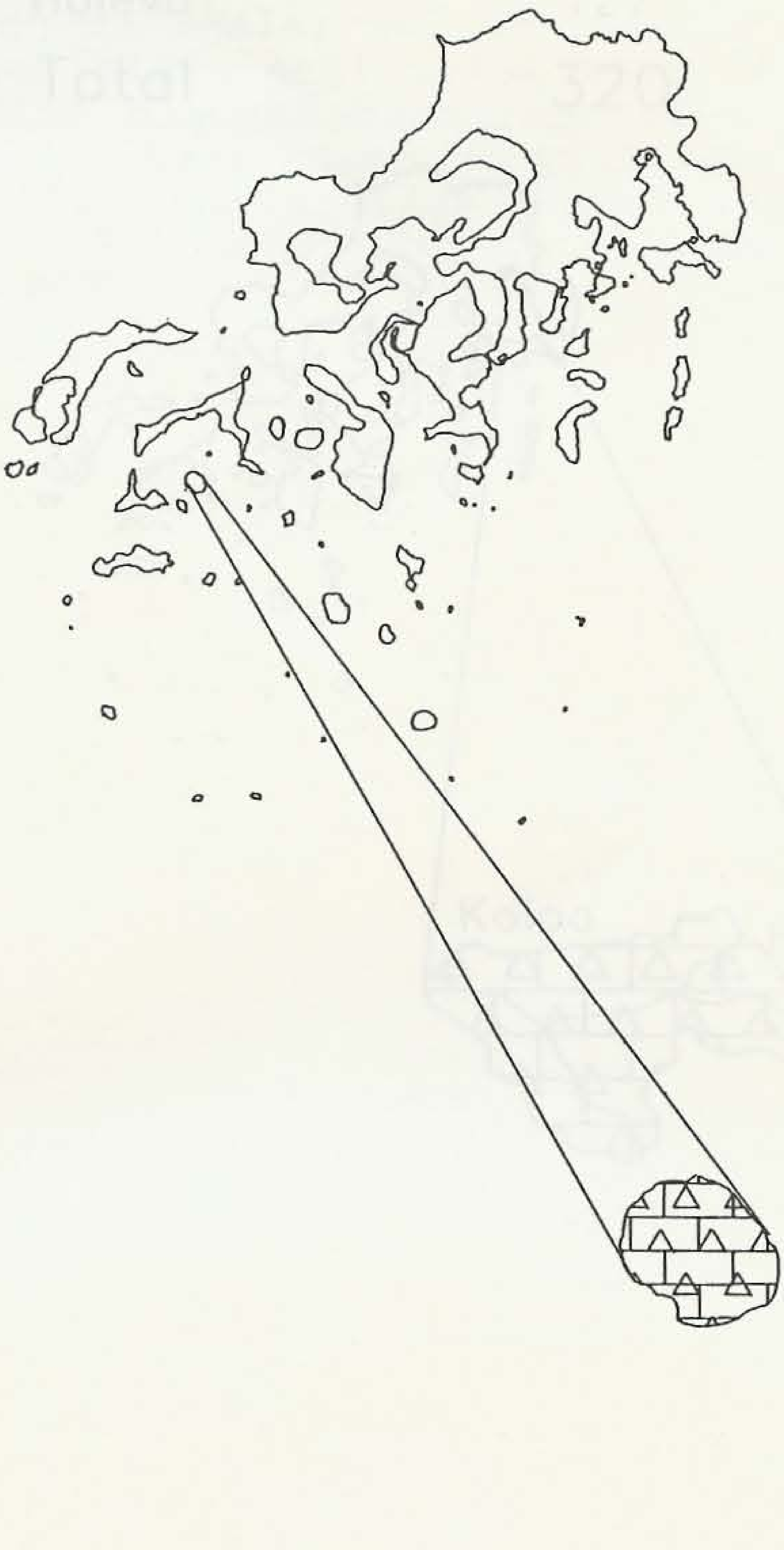


Fig. 6.4.13

6.4.14 'Ovaka

Hydrogeology

'Ovaka was visited in 1990 during a tour of inspection of small islands. It is a raised coral island with a volcanic ash soil in places. It is only up to 15 metres above sea level. Around the village and to the flat lying east are sandy soils. One well is located on the eastern side of the village. It contained salty water (3,370 uS/cm).

Water Supply

The water supply of the island is from rain water tanks and catchments.

Improvements

The only scope for improvement is in rain water tanks and improved guttering. From the available evidence there is little chance of obtaining fresh groundwater.

DIVISION VAVA'U

ISLAND 'OVAKA

LATITUDE $18^{0}45'S$

LONGITUDE $174^{0}06'W$

AREA	COASTLINE	ELEVATION
1.470 km^2	7.700 km	30 m

VILLAGES	POPULATION	HOUSEHOLDS
'Ovaka	113	24

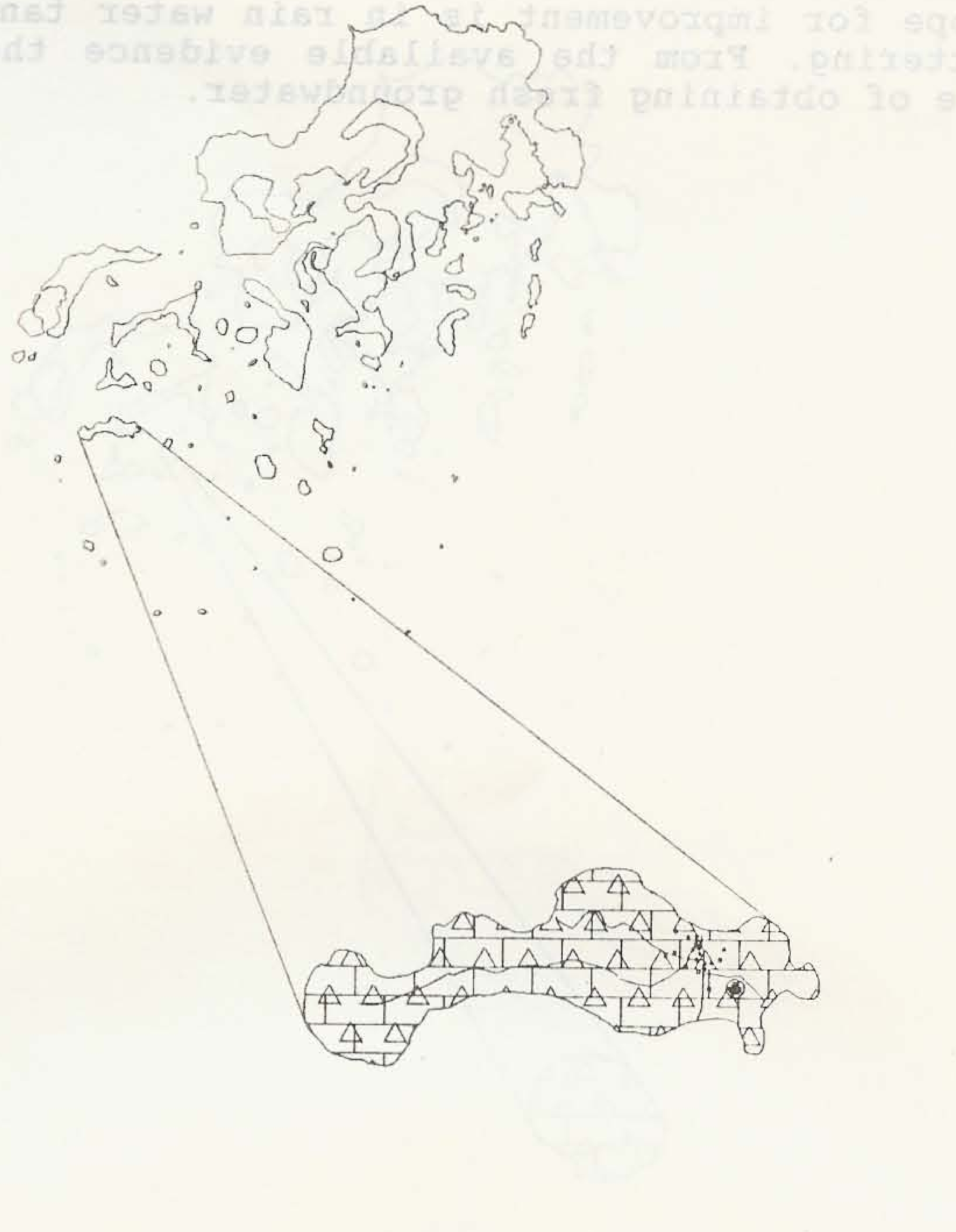


Fig. 6.4.14

6.5 Niuas Group

6.5 Niuas Group

6.5.1 Description

The Niuas are the three most northerly islands of the Kingdom of Tonga and are situated between Fiji and Western Samoa. Niua Fo'ou is frequently referred to as Tin Can Island, after the unique postal system of former times. Passing ships unable to anchor at the steep sided volcanic island would drop mail in sealed tin cans to be picked up by the island canoes. Niua Toputapu is called Keppel by other countries.

Tafahi is a spectacular volcanic cone similar to Kao in Ha'apai and is located about eight kilometres to the north of Niua Toputapu.

Access to the Niuas is by plane on a weekly basis or by passenger and cargo ferries on an irregular schedule. Frequent cancellations of flights and bad weather interruptions to shipping often strand visitors to the islands.

6.5.2 Niua Toputapu

Hydrogeology

Niua Toputapu is an island of two parts in the shape of a hat. There is a central east-west ridge (160 m) of volcanic rock rising above a wide rim of flat limestone. The three villages are located across the northern coast facing Tafahi.

The island was visited in 1992 for a census of wells and an appraisal of the hydrogeology. The limestone of the island is very permeable and similar to the coral limestone islands elsewhere in Tonga. A distinctive feature of the island is the freshwater spring called Niuatoa in the village of Hihifo. The spring discharges an estimated 20 l/s at a conductivity of 3000 uS/cm. It is caused by the progressive roof collapse of a shallow cave system.

The volcanic rocks of the central ridge do not form a significant aquifer due to their relatively low permeability. They have a volcanic ash soil which extends to the lower slopes. On most of the limestone rim the soils are sandy.

Hihifo has two wells behind the village (720 uS/cm) and Vaipoa (744 uS/cm) and Faleloa (980 uS/cm) each have one. Within Vaipoa and Faleloa there are several shallow hand dug wells. The water is fresh in these wells (272-533 uS/cm).

Water Supplies

The villages are supplied with piped water from the wells at the back of each village. The piped water supplies are supplemented with rainwater tanks and catchments. Recently there has been a cement rain water tank program to increase the number of storages on the island.

Improvements

Upgrading of the water supply is outlined in the Water Supply Master Plan. When this is implemented additional wells need to be drilled at the back of the villages at a separation of 150 metres from the existing wells. Improvements to roof guttering and rainwater tanks should be carried out.

DIVISION NIUAS

ISLAND NIUA TOPUTAPU

LATITUDE 15⁰57'S

LONGITUDE 173⁰45'W

AREA	COASTLINE	ELEVATION
15.745 km^2	18.360 km	160 m

VILLAGES	POPULATION	HOUSEHOLDS
Hihifo	683	122
Vaipoa	373	56
Falehau	265	37
Total	1321	215

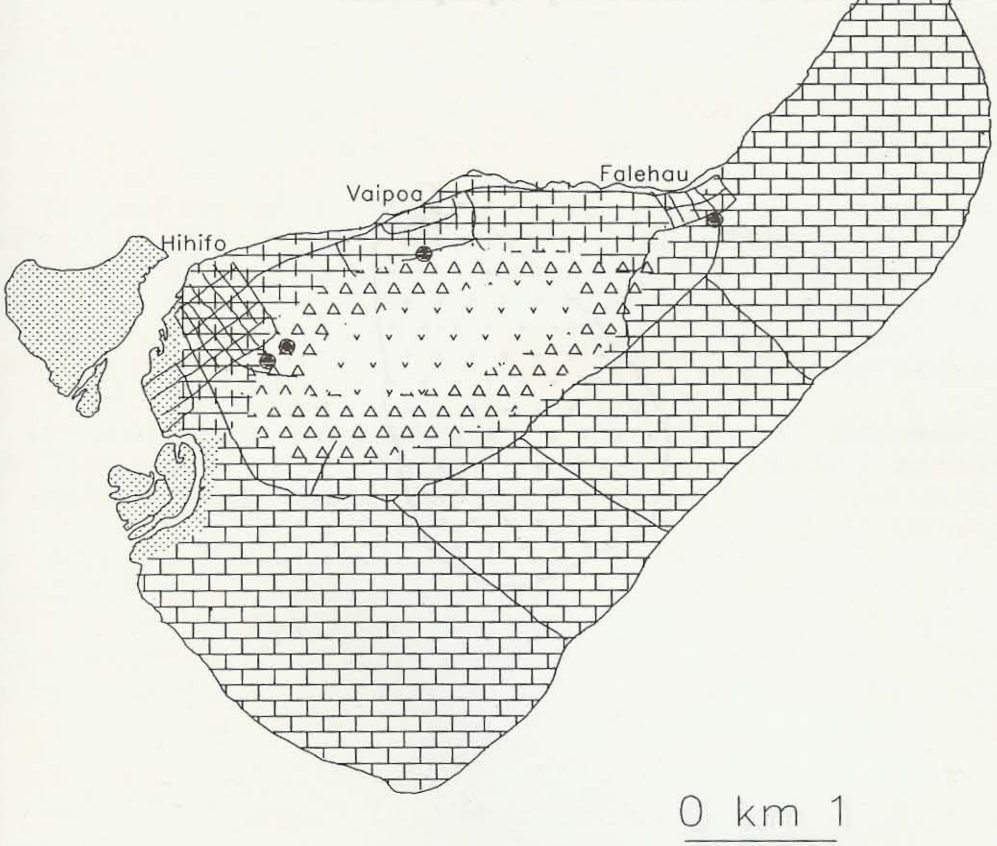


Fig. 6.5.2

6.5.3 Tafahi

Hydrogeology

The island of Tafahi is a spectacular and beautiful volcanic cone rising straight from the sea to a maximum elevation of 560 metres. It is comprised of lava and volcanic ash. There is slight development of a reef. The island is slightly elongated to the north-west, presumably in the direction of the prevailing winds during eruptions.

There are no wells on the island and groundwater resources are expected to be limited due to the low permeability of the volcanic rocks.

Water Supply

Water supply is entirely from rainwater in tanks and water catchments. In 1992 a total of 25 fibre glass rainwater tanks were installed and there are plans to install and additional 25.

Improvements

Improvements to water supply include increasing the amount of guttering and additional rainwater tanks. There is practically no scope for the development of groundwater with no access for drilling equipment.

DIVISION		ISLAND
NIUAS		TAFAHI
LATITUDE		LONGITUDE
15^{0} 51'S		173^{0} 43'W
AREA	COASTLINE	ELEVATION
3.556 km^{2}	7.351 km	560 m
VILLAGES	POPULATION	HOUSEHOLDS
Tafahi	284	46

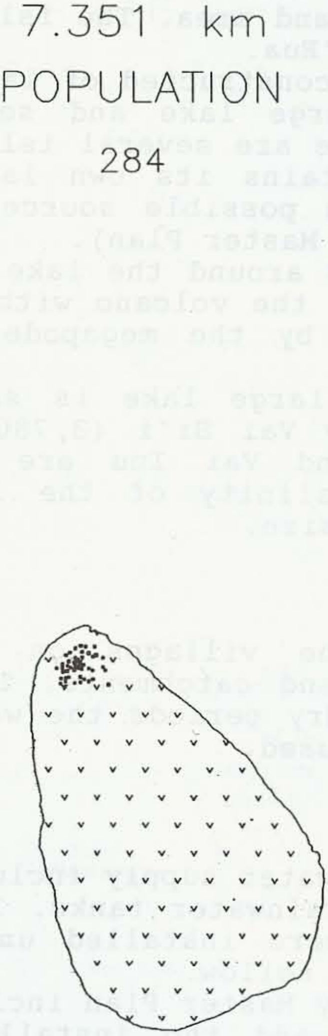


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Fig. 6.5.3

6.5.4 Niua Fo'ou

Hydrogeology

Niua Fo'ou was visited in 1992 to carry out a hydrogeological inspection and to test the quality of water in the crater lakes. The island is roughly circular in shape and forms a crater with steep sides and several enclosed lakes. The rim of the crater reaches a maximum elevation of 205 metres.

The volcano is still active, having erupted eight times in the last century. The most recent eruption was in 1945 at the southern end of the island. Lava covered about one quarter of the land area. The island was evacuated and people relocated on 'Eua.

The volcano is constructed of lava and ash layers. In the centre is a large lake and several smaller lakes. Within the large lake are several islands and one of these (motu molemole) contains its own lake. These lakes have been investigated as possible sources of water for water supply (Water Supply Master Plan).

On a few places around the lake there is evidence of the active nature of the volcano with sulphurous emissions and hot sands used by the megapode bird for incubating eggs.

Vai Lahi, the large lake is salty (4,230 to 7,188 uS/cm) and similarly Vai Si'i (3,780 uS/cm). The smaller lakes of Vai Fo and Vai Inu are brackish and fresh, respectively. The salinity of the lakes is somewhat in proportion to their size.

Water Supply

Water supply to the villages on Niua Fo'ou is from rainwater in tanks and catchments. There are no wells on the island. During dry periods the water from Vai Inu and Vai Fo is sometimes used.

Improvements

Improvements to the water supply include repairing the roof guttering and more rainwater tanks. In 1992 a total of 25 fibre glass tanks were installed under New Zealand aid, with a further 25 to follow.

The Water Supply Master Plan includes the upgrading of rainwater catchment and the installation of a pump and pipeline from Vai Fo. It is not practical to consider the use of groundwater due to the difficult access to the island and the expected low yields of wells in volcanic rock.

DIVISION	ISLAND
NIUAS	NIUA FO'OU

LATITUDE	LONGITUDE
$15^0 38'S$	$175^0 38'W$

AREA	COASTLINE	ELEVATION
$37.556\ km^2$	26.416 km	205 m

VILLAGES	POPULATION	HOUSEHOLDS
'Esia	142	30
Kolofo'ou	116	20
Sapa'ata	119	29
Fata'ulua	108	19
Mata'aho	29	6
Mu'a	54	14
Tongamama'o	66	15
Petani	129	22
Total	763	155

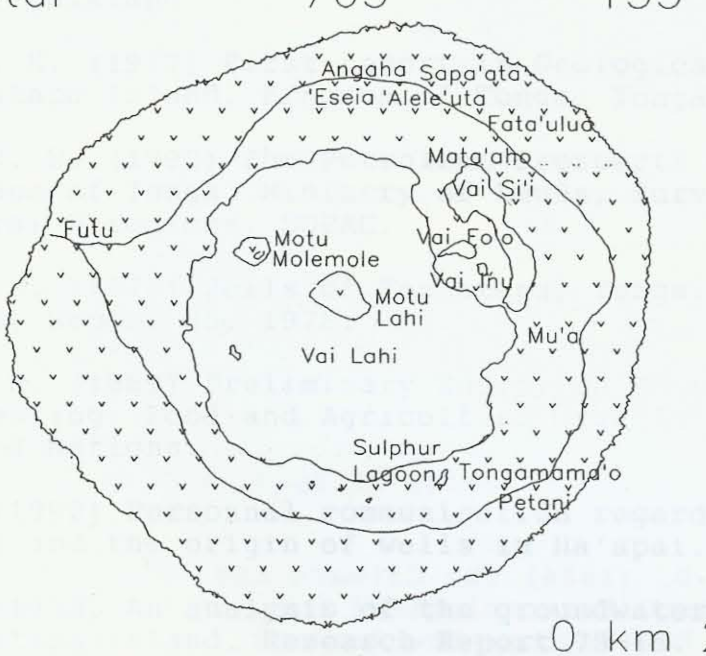

Fig. 6.5.4

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